CONSTRUCTION

OF THE

TUNNEL SYSTEM

OF THE

Hudson and Manhattan Railroad Company

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It is a curious coincidence that within a few months of the celebration of the Tercentenary of the discovery of the Hudson river by Henry Hudson there should also be celebrated the completion and placing in service of the first direct physical connection beneath the waters of the Hudson river between the states of New York and New Jersey.

The city of New York, located for the most part upon a group of islands bunched at the mouth of the Hudson river and thus separated in every direction from the mainland, has in the past and until the current year been cut off from connection with the mainland of the United States excepting by means of transportation by ferryboat, or to the north across the Harlem river. The railway entry into the city from the north and from the entire western portion of the United States has heretofore been limited to connection by the New York Central & Hudson River and its tributary lines, and even the West Shore Railroad, which comes under the same ownership, has of necessity terminated on the westerly shore of the Hudson river, and there has in consequence of the surrounding geographical conditions grown up on the westerly shore of the Hudson river in the state of New Jersey a great assemblage of all the trunk lines handling business in and out of New York city, with ferryboats the only means of communication afforded.

The Hudson river, for the length of Manhattan island, is practically a mile wide, but north of Hoboken the palisades on the New Jersey side of the river reduce the width of foreshore fronting the river to an exceeding narrow area. The consequence of this geographical situation is that all the trunk lines have become grouped on the Hoboken and Jersey City shores with the one exception of the West Shore terminating at Weehawken, which railway also has connection for passenger trains into the Pennsylvania Railroad station in Jersey City, so that to all intents and purposes communication by all these trunk line railways is within the district forming Hoboken and Jersey City. The development of this Jersey City water front has been by these terminal railways who acquired the riparian rights to lands under the water and filled in and extended the shore, thus forming the yards and terminals of these railways, precisely in the same manner that to-day the Central Railroad of New Jersey and the Pennsylvania Railroad are reclaiming and developing lands under water in the Communipaw and Greenville districts of Jersey City.

The railways terminating in Hoboken and Jersey City are as follows:

Delaware, Lackawanna & Western at Hoboken:

Erie Railroad, with its subsidiary lines, immediately south thereof in the vicinity of Pavonia avenue, Jersey City.

Pennsylvania Railroad, with its tributary and subsidiary lines, south of the Erie Railroad, and approximately at Exchange place, Jersey City. Entering over the tracks of the Pennsylvania Railroad are the New York, Susquehanna & Western, the Lehigh Valley, and the West Shore.

Central Railroad of New Jersey has its passenger terminal south of the Pennsylvania Railroad in Communipaw (Jersey City), but owing to the existence of the Morris Canal inlet, this location is practically cut off from street connection with Jersey City proper excepting by the long thoroughfare known as Johnston avenue, extending to the west. Passenger trains of the Baltimore & Ohio and the Philadelphia & Reading also enter the terminal station of the Central Railroad of New Jersey.

It is evident from the topography of the New Jersey shore above referred to that north of Hoboken the close proximity of the palisades to the shore front makes it inconvenient for any tunnel for railway connection landing near the water front to be constructed, since to make connection with any lines of railway it would be necessary to pass through the palisades to obtain a physical grade connection. This is the condition which has been met by the Pennsylvania Railroad with its tunnels and which was essential to that connection. Consequently, for local transportation it is necessary to locate any tunnel connection across the Hudson river at points either in Hoboken or in Jersey City. This frontage on the opposite New York side embraces the entire business districts of Manhattan island.

In addition to the steam railways, which control all the ferryboats operated across the Hudson river between New Jersey and New York, there are tributary to the ferries the various trolley car lines of the Public Service Corporation of New Jersey, feeding from the entire suburban district of New Jersey.

The geographical situation of New York City really makes the City Hall the center of an immensely populous territory forming the metropolitan district, whether on Long Island, Manhattan Island, The Bronx, Staten Island or within the state of New Jersey, all being tributary to New York City. In the latter portion of this metropolitan district are embraced the counties of Hudson, Bergen, Essex and Union, representing a population of one and a third million people directly tributary to New York City and largely transacting their daily business in New York City. In Hudson county alone there is a population of some 537,231 persons, and this county is composed practically of a narrow strip fronting on the Hudson river, the bulk of its population being in Jersey City and Hoboken, and in the past this population has had no means of intercommunication with New York City excepting by the ferryboats having terminals at Weehawken, at Fourteenth street, Hoboken; at Hudson place, Hoboken; at Pavonia avenue, Jersey City, and at Exchange place, Jersey City. It is, therefore, obvious that apart altogether from through railway business terminating on the various trunk railways aforementioned, there has been, and is now, a tremendous demand for more rapid communication for the great population in the suburban district of New Jersey tributary to New York. Close estimates have been made of the ferry traffic across the Hudson river, and conservative counts indicate that it is not less than 125,000,000 per year, and with the increased facilities afforded by the tunnels it is thought that the annual increase in this traffic will be much greater than is indicated by the ferry traffic in the past.

The suburban district of New Jersey for residential purposes is at least as beautiful and as attractive in every respect as any section of country surrounding New York City, and to the commuting population the attractiveness of any locality as a place of residence is largely governed by its accessibility measured by the factor of time required in travel between the home and the place of business.

About the year 1873, the Hudson River Tunnel Company was organized by DeWitt Clinton Haskins with capital largely advanced by Trenor Park, to carry out the project put forward by Col. Haskins to tunnel the Hudson river for the purpose of connecting New Jersey and New York. At that time the center of the fashionable residential district of New York City was located at Washington square and the two railways then, as now, doing the largest suburban business were the Delaware, Lackawanna & Western and the Erie. Col. Haskins consequently located the line of the tunnel in Jersey City at the foot of Fifteenth street, this point being approximately midway between the terminals of the Lackawanna and the Erie, and the idea as projected by him was to extend under the streets partly, but largely under private property in a direct line to a terminal station to be located on private property in the vicinity of Washington square. The entire plan

was predicated on the assumption that the steam trains of the Lackawanna and the Erie would operate through this tunnel directly into a union station in the neighborhood of Washington square. This plan left out of consideration the Pennsylvania and all other railways terminating in Jersey City, and with our present knowledge of the conditions of operation, it is certain that even had these tunnels been constructed at that time the use of the same by steam trains would have been an impossibility, and the tunnels would probably have had to await the development of other motive power than steam before they could have been operated successfully for passenger traffic. During the subsequent long period of troubles and reorganizations through which the companies passed, there developed complete changes in the operating conditions, not only in New York City, but also in Jersey City and Hoboken, and at the time of the last reorganization and the formation of the present company it had become necessary to change entirely the proposed scheme of operation of these tunnels to meet the new conditions which had arisen in respect to transportation. The original location of the so-called Uptown Tunnels from Fifteenth street, Jersey City, to the foot of Morton street, New York, was by no means ideal for the uptown business, and in no respect whatever was the location serviceable for handling the downtown business. At the time of the last reorganization of the tunnel company it was essential that the possibility of constructing a tunnel across the river should be demonstrated before anything else could be done, and it was, therefore, necessary to concentrate work on one tube to make a connection from shore to shore. The numerous difficulties and obstacles with which the previous companies and contractors had been met had left the work in a condition which made the general public extremely doubtful as to whether or not this could ever be accomplished, and it was fully convinced that the project could not be carried out to successful completion. The work in Jersey City had originally been commenced with the idea of constructing one tunnel sufficiently large for double tracks, but before any considerable portion of the tunnel had been constructed under the earlier methods it was demonstrated clearly that the difficulties to be encountered in the endeavor to construct a gigantic tunnel for two standard steam railway tracks were so great that this idea was early abandoned and the twin tunnels were commenced. The work executed by Col. Haskins was done under air pressure, the tunnel lining consisting in the first instance of an external shell of thin sheet-iron plates, 2½ ft. wide, ¼ in. thick, in small segments connected by 3-in. angle irons, which could be put together by hand, and the segments were braced for the support of the soil outside. On the completion of a section of excavation in this manner the internal brick lining was constructed, having a finished internal section oval in form 16 ft. wide and 18 ft. high.

This type of construction was carried on in the southerly tube from Jersey City a distance of some 500 ft. and in the northerly tube a distance of approximately 2,000 ft. Neither the alignment nor grade could be maintained correctly, and a good deal of the portions so constructed had exceedingly bad curvature. After suspension of the work carried on by Col. Haskins, work was resumed under contract by using a shield and iron plate lining, this lining having an internal diameter of 18 ft. 2 in., circular in section. At the time of the last reorganization the work had been constructed to the following extent:

North tunnel from New Jersey shaft.....	3,916 ft.
North tunnel from New York shaft.....	160 ft.
South tunnel from New Jersey shaft.....	570 ft.

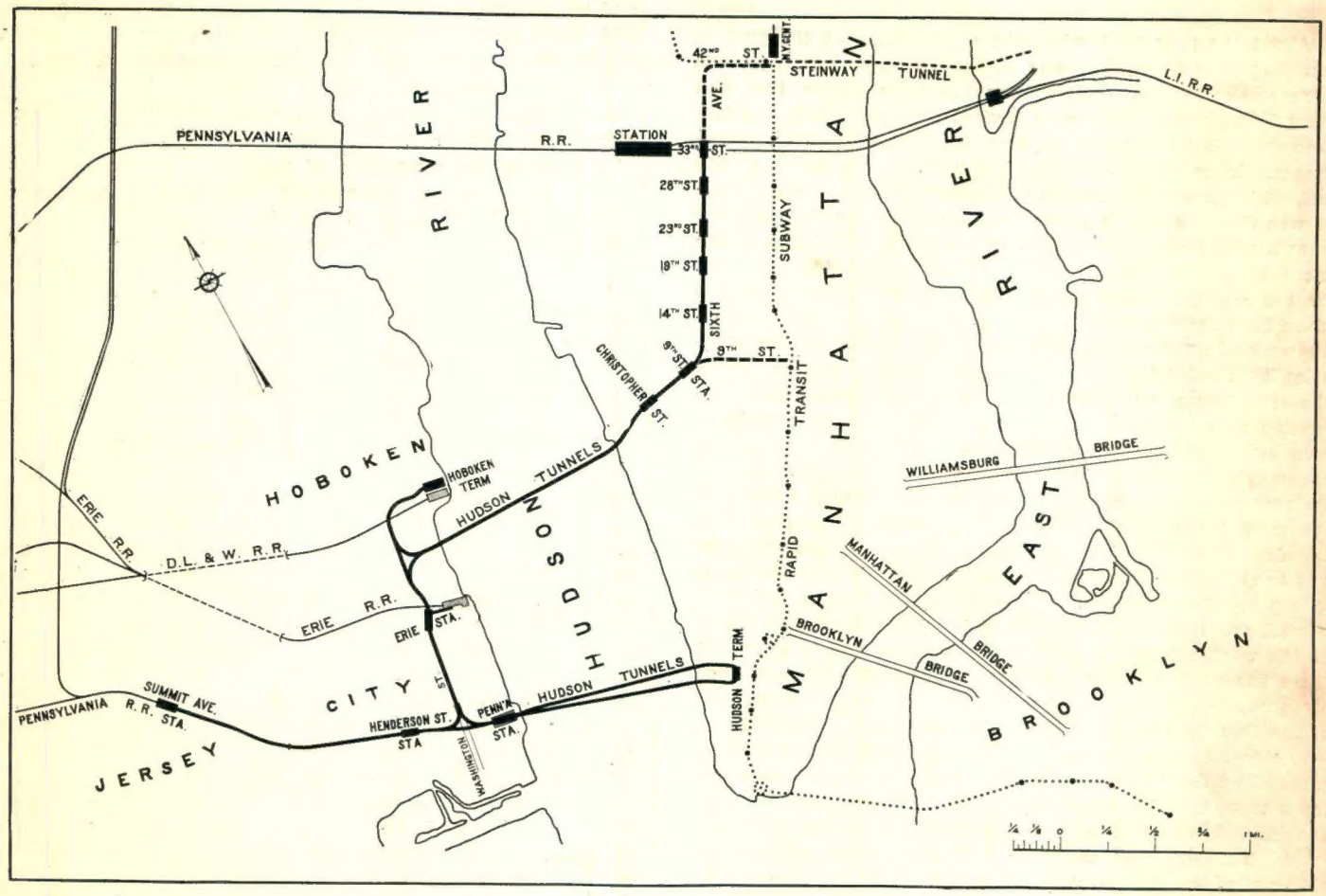
At the time of the suspension of work last mentioned the shield had advanced to a point where there existed immediately in front of it in the north tunnel a reef of rock which extends all along the shore of Manhattan island in the downtown section. When the reorganization was effected by the New York & Jersey Railway Company (now the Hudson & Manhattan Railroad Company), the work was resumed by the Hudson Improvement Company, in order to demonstrate, as before mentioned, the feasibility of building a tunnel under the river from shore to shore.

All work was concentrated on completing the northerly tube by the use of the shield and iron lining plates 18 ft. 2 in. in diameter, with the idea of constructing a double track railway in one tunnel with specially designed narrow equipment, similar to the tubes first built in London, and to operate these small cars by electric power. This tunnel was completed from Jersey City to New York on March 11, 1904. As the work proceeded satisfactorily, questions of the general development of the project arose, and it became obvious that if the tunnel were to be successful for operation of passenger traffic it should be operated with equipment of about similar size to that in general use, and consequently it was decided that a single tube with the special type of narrow equipment would not be at all satisfactory. Work was, therefore, resumed on the second parallel tube, adopting a size which would enable a car of satisfactory dimensions to be operated through the same, determined as 15 ft. 3 in. internal diameter. At the same time the undesirable terminal location in Jersey City, originally contemplated, was abandoned, and it was then decided to relocate the line to extend northerly under the Lackawanna company's property to Hoboken with a terminal at the foot of Hudson place, where the terminal of the Lackawanna as well as the terminals of the trolley cars of the Public Service Corporation of New Jersey are located; this location furnishing a definite source of business to accrue to the tunnels. Satisfactory and amicable arrangements were made with the Public Service Corporation for a terminal beneath its property, a part of which, however, is beneath the streets of Hoboken, the rights to the use of which were provided by the franchises. At the same time the Erie desired to be considered in relation to this means of transportation under the river between Jersey City and New York, and in consequence lines were filed for a location extending also southerly to the Erie, and, to complete the operating proposition, lines were extended to connect Hoboken with the Erie. As this project developed it became evident that while provision was being made for uptown business no provision whatsoever was being made in this scheme for any downtown business, and, further, that the uptown terminal at Christopher and Greenwich streets was inadequate to care for or to benefit the traveling public desiring access to the business centers in New York City. Application was, therefore, made to the Board of Rapid Transit Commissioners for a franchise to change the New York terminal by extending the tunnels in New York City, from the terminal above mentioned, under Christopher street and Sixth avenue to a terminal under private property at Thirty-third street and Broadway, and while this application was pending influence was brought to bear to change this terminal to a point at Fourth avenue and Ninth street. The franchise granted by the Board of Rapid Transit Railway Commissioners ultimately provided for the two terminals—one at Thirty-third street and Broadway and one at Fourth avenue and Ninth street; these two terminals affording connection with the Interborough Rapid Transit subway and with the surface and elevated lines in the shopping district in Sixth avenue, and active work proceeded on the construction of these several lines.

The routes and terminals above mentioned would, when constructed, provide admirable facilities for passengers between the Erie and the Lackawanna and uptown New York, but no provision had thus far been made for the much heavier business coming daily into the downtown district, and which involved a larger proportion of the commuting business between New York City and the suburbs. To plan a line to the downtown district the first essential was to locate a site on which to construct a terminal, and as at this time the Pennsylvania had commenced work on its extension into

New York City, uptown, the company was desirous of co-operating in any project which would give rapid transit to the downtown district for its patrons, and the line for the downtown tunnels of the Hudson & Manhattan was finally located from the Pennsylvania station in Jersey City to a terminal on private property fronting on Church street and extending from Cortlandt street to Fulton street in New York City. This terminal was constructed with a series of five loop tracks, trains entering at the Cortlandt street end and departing at the Fulton street end, thus obviating stub end terminal operation. These downtown tunnels were located with the idea not only of a station under the trainshed of the Pennsylvania Railroad in Jersey City, but with a view of making a physical connection with the Pennsylvania tracks to the west. A connection between the uptown system and the downtown system of a very satisfactory transfer connection for passengers between the two terminals. This complete plan will make a connection between the New York Central and the New Haven and all the railways before mentioned terminating in New Jersey. Besides this, the station at Thirty-third street and Sixth avenue will be only a block from the Pennsylvania and the Long Island Railroad.

Actual count of passengers handled on the ferries between New York and New Jersey indicates that the maximum hour of travel in one direction is westbound between 5 and 6 p. m., during which period the percentage of travel is 10.69 of the entire daily movement. The travel eastbound reaches the maximum between 7 and 8 a. m., when 7.49 per cent. of the entire day's traffic is handled. These percentages are constant factors in determining the maximum conditions regu-



Hudson and Manhattan Tunnel System.

completed the project as now carried out in actual fact. The system as now operating connects, therefore, the main trunk lines terminating in New Jersey, excepting the Central Railroad of New Jersey, with both the uptown and downtown districts of New York City, and the Central Railroad of New Jersey will also in the future be taken care of.

Prior to the completion of the lines to Thirty-third street and Broadway it was considered desirable, in order to make the system complete, to extend the uptown tunnels northerly under Sixth avenue to Forty-second street, thence to the Grand Central Station, where the terminal station of the Hudson & Manhattan will be in immediate contiguity, not only with the Grand Central Station, which is now being constructed as a depressed station, but also with the express station of the Interborough Rapid Transit subway. This terminal of the Hudson & Manhattan will be approximately at the same level as the suburban station of the New York Central & Hudson River, and this will consequently permit lating traffic operation. The tunnels are constructed of size suitable for operation of the usual type of suburban car and for operation of multiple unit trains of eight cars on a minimum headway of 1½ minutes. Figured on the percentages, there is provision for future development of transportation on the company's lines between New York and New Jersey considerably beyond the entire present passenger movement in addition to the heavy local business accruing from local traffic on both sides of the river. The passenger traffic reaching the ferries on the New Jersey side by trolley cars is approximately 150,000 per day in both directions, and the bulk of this travel is from points at some distance from the ferries, where the tunnel stations will be of direct benefit. At the Jersey City ferries of the Pennsylvania Railroad the morning and evening congestion of the trolley car service is very great; so much so that from the residential district on Jersey heights the average time of travel on trolley cars to reach those ferries at Jersey City is 20 minutes. This district will

be immediately served by the tunnel station at Summit avenue, from which the running time of trains to the Church street terminal, New York City, will be 10 minutes. As no ferry across the Hudson River at the present time operates in less than 7½ minutes interval, and the bulk of the ferries is not less than 10 minutes, and the tunnel trains now operate at 3 minutes interval and will ultimately operate on 1½ minutes, the saving in time to the local population of Jersey City and Hoboken, apart altogether from the railway traffic, is very obvious. The difference is still more marked for all traffic into the uptown district, and it is safe to say that for railway passengers terminating at the several points on the Jersey side destined to the downtown district in New York City, using the river tunnels, the saving in time will be 15 minutes in each direction, and to passengers to the uptown district the saving will be in each direction from 20 to 30 minutes.

ORGANIZATION AND WORK PLANTS.

About the year 1902, when the organization of the present company was effected, it was desired to let contracts for the construction of the uptown tunnel between Jersey City and New York, and tenders were invited from numerous contractors for this work to be constructed to specification requirements. In response to all the invitations there was only one bid, which was by no means satisfactory to the company, and it was then decided to carry out all the work with the company's own forces. At that time the construction and equipment of the entire system as planned was to be executed by the Hudson Improvement Company, which company has since been merged into the Hudson Companies, and the latter has carried out to completion the entire system now in operation by the Hudson & Manhattan Railroad Company. With the exception of the subway portion of the Sixth avenue extension all work has been executed directly by the company's own employees under the direction and management of the company's engineers, and this arrangement has proved eminently satisfactory, particularly as the largest portion of the work has been executed under air pressure involving all the difficulties and dangers of such work, and the company has in consequence had under better control all questions relating to the possibility of injuries which might have occurred, and it is a matter of great pride that in the execution of the work along the lines now completed and in operation there has been an almost entire absence of fatal injury from air pressure work, or caisson disease, and very few injuries of moment to employees from any other causes.

The work recently completed involved the construction of some 15.6 miles of track almost the whole of which is in single track tunnel. With the exception of the portion of the Sixth avenue extension the whole of the work is below mean sea level. This includes the construction work on the various stations, which will be referred to later.

A great added advantage in carrying out the work with the company's own organization is the obvious fact that the work could proceed without designing and planning all the details in advance. This was of enormous advantage, as the conditions changed so frequently during the execution of the work that to have carried out the construction by contract under the conditions would have involved the company in constant difficulties with the contractors, owing to the changes, not only in the details, but in matters of policy and of importance. Therefore, the arrangement for carrying out the work with the company's own forces was most elastic and conduced most thoroughly to the rapid and efficient execution of the work, and as the operating, electrical and construction departments were all under one head the co-operation was complete and the co-ordination of all interests was most effective.

As this entire work involved underground construction, except at isolated points, the construction could only be carried on from a limited number of places designated "Work Plants," at each of which points a complete power plant was installed. These plants were located as follows:

1. At the foot of Fifteenth street, Jersey City, at which point the original shaft, commenced by Colonel Haskins, was located. This plant consisted of a steel frame building covered with sheet metal, and contained a boiler plant of 1,800 h.p. boiler capacity, high and low pressure air compressors, hydraulic pumps operated to 5,000 lbs. pressure with an accumulator loaded to 1,500 lbs. pressure, generating plant for 250-volt direct current, medical lock and doctor's office, bath room, locker room and dressing room for workmen and various offices. This plant was fortunately located in the yards of the Delaware, Lackawanna & Western, where deliveries of materials were made on tracks alongside the works, and by lease from the D., L. & W. the company was enabled to dump excavated material from the tunnels into scows at the bulkhead adjacent to the works for disposal at sea. From this plant the two uptown river tunnels were constructed toward and for the entire distance to New York, the two tunnels west and north toward Hoboken, the two tunnels west and south toward the Erie Railroad, and also caissons Nos. 1, 2 and 3, hereinafter referred to.

2. At Hoboken. At this point the terminal station was constructed in open excavation, but on account of the necessity of expediting the completion of the Hoboken tunnels a subsidiary plant was installed and the two tunnels from Hoboken Terminal west and south to join the river tunnels were also constructed with shields, in the same manner as the tunnels were constructed from the Fifteenth street plant.

3. Foot of Morton street, New York. This plant was constructed on the property of the Department of Docks and Ferries exterior to West street at the site of the original work commenced by Colonel Haskins and where a shaft had at that time been constructed in caisson. This plant consisted of a steel frame building covered with sheet metal and contained boilers of 1,200 h.p. boiler capacity, high and low pressure air compressors, and other equipment, generally similar to the plant at Fifteenth street shaft above mentioned.

From the Morton street plant two tunnels were constructed eastward under West street, thence by a reverse curve into and under Morton street, thence curving to the left into and under Greenwich street, thence northerly under Greenwich street to Christopher street, thence curving to the right into and under Christopher street, thence easterly under Christopher street into and under Sixth avenue, thence northerly under Sixth avenue to Twelfth street. The shield in the eastbound tunnel turned from Sixth avenue into Ninth street and extended under Ninth street clear of the line of Sixth avenue, and a shield installed at the intersection of Sixth avenue and Ninth street executed the work northerly from that point to Twelfth street. The shield in the westbound tunnel continued to Twelfth street, where it passed out into open cut constructed subway. No tunnels were constructed westerly from Morton street plant. The location of this plant permitted the receipt of materials and the disposal of excavated material by boat or lighter over the bulkhead at the water front at the head of the French Line dock.

4. At Ninth street and Sixth avenue, New York. This plant was erected on private property with the expectation of proceeding immediately with the work under Ninth street, and was used for the junction enlargement and for other work on Sixth avenue in that immediate vicinity, but this was only a subsidiary plant in connection with the plant at Morton street, and was equipped with high-pressure air compressors and had 370-h.p. boiler capacity, besides dressing rooms, lockers, etc.

5. Washington street plant. This plant was located on Washington street, between Bay and First streets, Jersey City, immediately adjoining the permanent power house of the company erected at that point. This plant contained 1,200-h.p. boiler capacity, water-tube boilers, a modern and efficient air compressor plant for high and low pressure air, with all the other arrangements installed at the several plants. This location was selected as being about the center of gravity of

the system. The shaft was sunk in the center of Washington street to the grade of the two tunnels and work was carried on in each tunnel, towards both the north and south, from this plant, the southerly legs bifurcating to connect westerly to the Newark line over the Pennsylvania tracks and easterly to Church street terminal, New York. In addition to the regular tunnel work constructed from this plant, the intake and overflow tunnels for the power house were constructed, as well as the foundation work for the permanent power house. This location was served by the yard tracks of the Pennsylvania Railroad entering the property.

6. Pier C plant. This plant was located at the foot of York street, between Piers B and C, Jersey City. As the lines of the downtown tunnels were located under the trainshed of the Pennsylvania Railroad, in order to execute all construction work at this point it was necessary to locate the point of attack at considerable distance from the actual tunnels. To do this the company leased from the Pennsylvania Railroad a piece of property south of York street at the water front, together with a portion of the bulkhead and Pier C. The shaft was constructed by sinking in the water at the head of the dock an iron shell into the mud and through the mud to bedrock, and then, after sealing the shaft to the rock, a shaft in the rock was excavated to a depth of approximately 90 ft. below the surface. From the bottom of this shaft a heading was driven northerly a distance of some 300 ft., in which was installed a three-track narrow gauge railway on which cars loaded with excavated material from the tunnels and supplies going into the work were hauled by an electrical mining locomotive with overhead trolley. From this heading the two river tunnels towards New York were driven, the enlargements for the Pennsylvania station and the five tunnels west of the Pennsylvania station were constructed. Of the five tracks west just referred to, Nos. 1 and 5 are direct connections to and from Hoboken, Nos. 2 and 4 direct connections to and from Newark, and No. 3 is a stub-end crossover track. This plant was equipped with 1,800-h.p. boiler capacity, high and low pressure air compressors, hydraulic pumps and electric generators generally similar to the other principal plants.

7. Dey street, New York. This plant included also a separate and distinct plant put in for the construction of the caissons and foundations of the Church street terminal station and buildings, but for the construction of the approaches and the tunnels from the New York side a plant was installed in the cellars, or basements, of a number of adjacent buildings owned by the company, or leased, and made a very necessary but most expensive plant to operate. This plant contained 1,775-h.p. boiler capacity, with the usual compressors, hydraulic machinery, locker and dressing rooms, medical lock, doctors' quarters, etc. In addition to this steam power was also drawn at times from an outside concern furnishing steam commercially, and during the latter portions of the work, the terminal building being completed prior to the completion of the tunnels, the boiler plant installed in the building was drawn upon quite largely for power.

8. For the execution of the Railroad avenue work in Jersey City a small subsidiary plant was installed on Railroad avenue near Warren street. This plant was equipped with compressors, etc., operated electrically by current from the plant at Pier C.

To indicate the magnitude of the work carried on from these various plants it should be noted that for the work of construction, since 1902, there was consumed 240,000 tons of coal, and from the commencement of construction work in February, 1902, to the completion of air pressure work on June 26, 1909, the air compressor plant connected with the work was never out of operation.

During the most active period of construction the work was divided into five divisions, each in charge of a works manager. These divisions were as follows:

(a) The work in New York City, uptown.

(b) The work in Hoboken, carried on from Fifteenth street shaft, including the work at the Hoboken terminal, the uptown river tunnels and the junction enlargements located in Hoboken and in the northerly part of Jersey City.

(c) The tunnels in Washington street, Jersey City, north and south, executed from Washington street plant.

(d) The work at Jersey City, downtown, involving the river tunnels, the Pennsylvania station, Railroad avenue extension from works centered at Pier C shaft.

(e) The Church street terminal construction and the downtown New York tunnels from the works centered in Dey street and at the site of the Church street terminal.

During the period of greatest activity the company had as many as 8,400 men employed at one time.

All work executed under air pressure was under the supervision of the medical staff in charge of Dr. A. J. Loomis, chief medical officer, with three assistants, located at suitable points on the works. The medical staff examined every man applying for work under air pressure, and no men were engaged for this class of work without a certificate from the medical department to the effect that they were physically suitable for such work. The construction department, as far as possible, faithfully regarded the examination and reports of the medical staff and to this fact is attributable in a great measure the entire absence of difficulties from caisson disease. On the construction work carried out under air pressure the medical staff examined and passed 29,000 men for work in pressure over 20 lbs. and 10,400 men for work in pressure under 20 lbs.

At central stations, where the assistant medical officers were resident on the work, a hospital air lock was equipped at each station, with dressing room and all provisions and appliances for rendering first aid to sick and injured, and the hours of the assistant medical officers were arranged so that at least one assistant was on the work at all hours of the day and night.

TUNNEL CONSTRUCTION.

In laying out the lines adopted by the company for construction, the general principle of tube construction was adhered to throughout. As before stated, the cars designed for operation with the necessary clearances required a circular tube having a diameter of 15 ft. 3 in. inside, and in such sections of the work where concrete lining was used the same general diameter and section were adhered to. In the case of the subway construction in Sixth avenue, while the two tracks were constructed together the same general type was adhered to by the construction of a central dividing wall and giving to it an arch roof corresponding closely to the section provided by the circular tube. This same general section was also followed in the construction of stations, so as to make the design harmonize with the tube construction, and the stations wherever possible were built in arches, and, where feasible, the arches were groined, giving not only a pleasing form of construction, but one which reduces maintenance costs to a minimum and is at the same time structurally the strongest possible section.

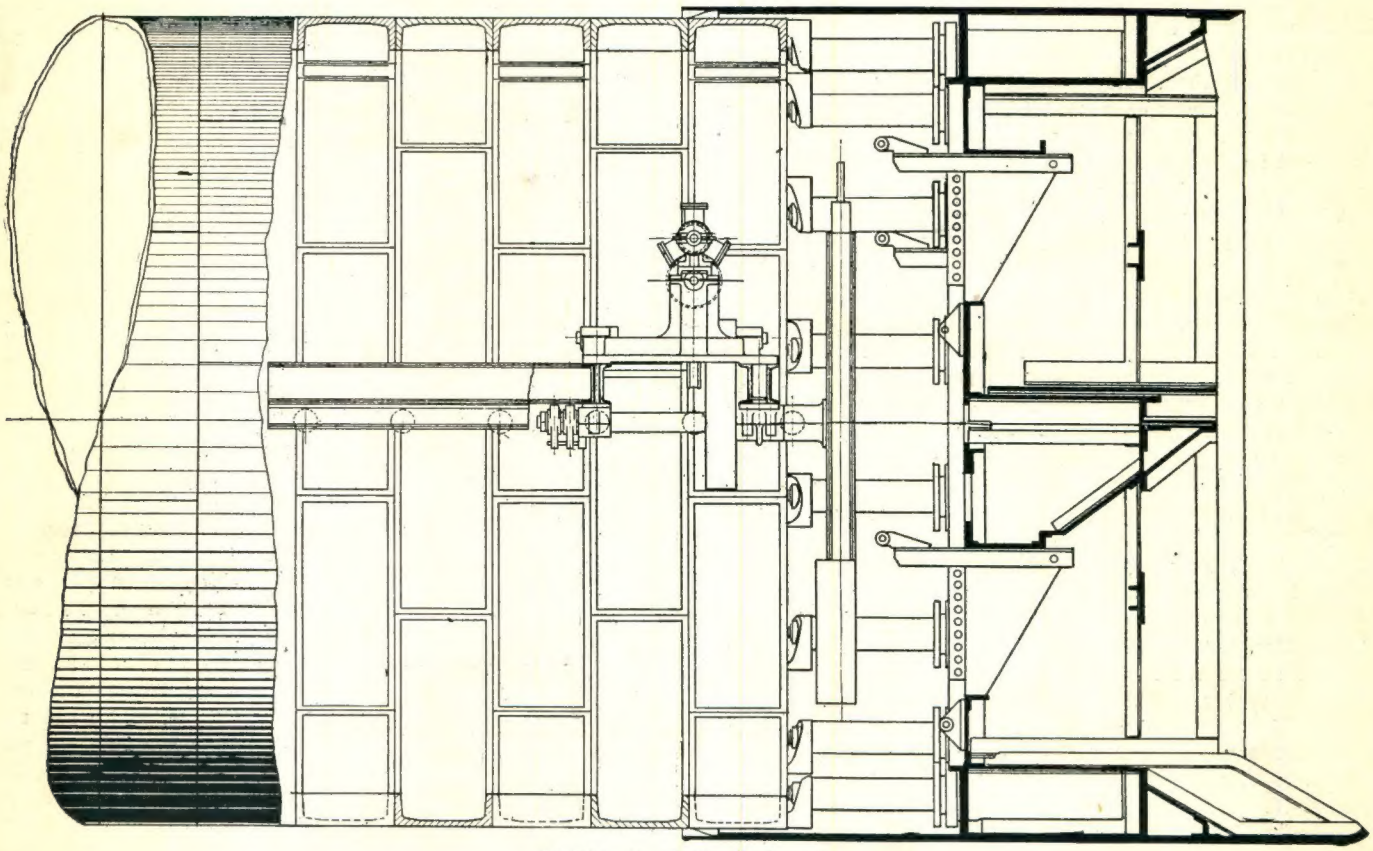
The work of construction along these lines has, owing to the geological conditions, involved almost every possible combination of underground construction. Comparatively little of the work has been in solid rock formation, the greater portion being either in soft ground or under conditions of partial rock bottom overlaid by soft ground.

The construction of the river tunnels, both uptown and downtown, has been very similar. The original tunnel constructed partly by the earlier companies was completed of the same diameter as the earlier construction; that is to say, the westbound tunnel was continued all the way from Jersey City to the shaft at the foot of Morton street, New York, lined with iron 18 ft. 2 in. inside diameter. The shield with which this tunnel was constructed was in place in the tunnel when

the work was taken over by the present company, and, with modifications of construction, this shield was made adaptable for continuing the work with lining of the diameter mentioned; avoiding the necessity of reconstruction of a shield entirely for this tunnel.

After this tunnel was completed, however, of the size stated above, it was lined internally with concrete to the same internal diameter as the other tunnels throughout, and this difference in size enabled many of the irregularities in the earlier construction to be straightened out and adjusted. With this exception, all the other tunnels, as before stated, have been constructed of the same general size.

For all the remaining river tunnels, hydraulic shields were designed for the peculiar conditions under which they were to be used, but these shields have been practically similar in design throughout. They consist of an external shell, the front end of which is shod with heavy steel cutting edge castings in segments, and the tail end of the shield overlaps



Shield in Soft Material.

and telescopes outside the plate lining of the finished tunnel as the lining is erected and the shield advances. Each shield is equipped with 16 hydraulic jacks, each jack 8 in. in diameter by 30-in. stroke, which allows for the erection of the lining in 24-in. rings with a little additional margin for clearance. The jacks are operated from blocks of valves dividing the shield into quadrants, and in such a manner that any one or more jacks may be operated independently or collectively.

Generally speaking, the erectors for the erection of the lining plates were operated independently of the shields, using pneumatic engines for rotating the erector and a hydraulic ram for the lifting operation.

The hydraulic power installed for the operation of the shields was designed for working at the maximum working pressure of 5,000 lbs. per square inch, and the shields were designed of strength sufficient to operate under this pressure. The great strength of the shields as designed enabled them to be advanced through the silt formation of the bed of the Hudson river practically without admitting any silt into the tunnels for removal, which enabled record time in tunnel construction to be made. This was carried to such an extent that as much as 72 ft. of finished tunnel has been constructed in a single day of 24 hours in one heading.

All work under the river was carried on under air pressure throughout, this pressure varying according to the depth at which work was executed and also according to the conditions of the soil, but the highest pressure used was 48 lbs. per square inch above the normal atmospheric pressure; this high pressure being used for a very short period only, and usually the pressure did not exceed 35 lbs. per square inch.

The usual arrangement of the air locks installed was to erect two standard material air locks side by side, these locks being large enough at the doors to permit the passage of iron dump cars of narrow gauge, with a capacity of one cubic yd., and the locks were of length sufficient to permit of locking through three of these cars at one time. The material locks were placed at a low elevation in the tunnels to permit of extending a single, narrow gauge construction track through each lock, and these tracks were fitted with scissors crossings at the ends of the locks to permit of the use of the locks in both directions.

An emergency lock was installed in the bulkhead over the material locks and as high in the tunnel as possible. These locks were of diameter sufficient to enable a man to sit in a comfortable position and were long enough to receive a gang of about 15 men at once.

The groups of air locks constructed in the tunnels were in every case installed in concrete walls, or bulkheads, from 3 to 4 ft. thick, and the locks were fitted with thrust rings on the outside to resist the air pressure and to hold the locks in place.

In addition to the material and emergency locks, each air bulkhead was also fitted with a pipe lock approximately 35 ft. long and about 18 in. in diameter, with a flap valve on the

pressure side and a gate valve on the external side, through which were handled long pipes, rails, timbers, etc., which would not pass through the material locks.

In all cases of tunnel work being carried on, when the pressure exceeded 20 lbs. per square in. for regular operating use, as in the river sections, double air bulkheads were installed so as to make two stages of pressure, making decompression easier for the employees, and reducing very greatly the risks attendant upon coming out of air pressure rapidly.

The iron lining used in the construction of all tunnels has been maintained at the same weight throughout, owing to the fact that all this work is below sea level, and with considerable water pressure upon the same. Each iron segmental plate lining ring consists of 9 segments of equal length with a key plate for the closure, the key having the same length as the pitch centers of the bolts. The plates are flanged on all sides, forming a series of circumferential joints and connected together by longitudinal joints, all joints being machine surfaced each complete ring of plates is connected to the preceding ring by 55 bolts and there are 3 bolts in each segmental joint. The bolts are 1¼ in. in diameter and were made with cold rolled threads.

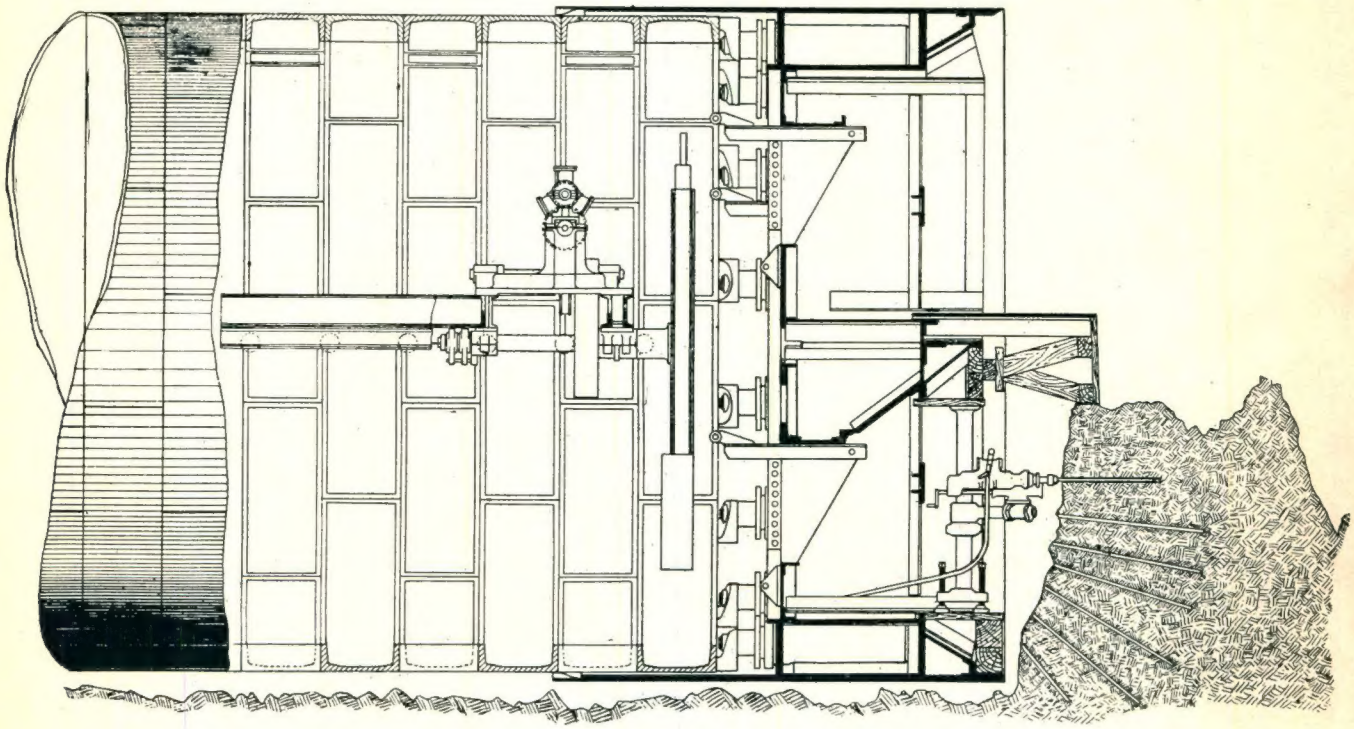
Generally speaking, the longitudinal joints were staggered by placing the key in different positions so as to break the continuity of the longitudinal joints and to give greater rigidity to the finished construction.

Errors in alignment occurring in the construction of the tunnels were corrected at each advance of the shield, according to instrumental observations, by the insertion of taper rings, which enabled the center line of the tunnel to be deflected, horizontally or vertically, and the use of these taper rings further enabled the tunnels to be constructed on curves where curvature is necessary for the alignment; a record, in this respect, having been made in driving the tunnels on approximately a 150-ft. radius curve from Morton street into Greenwich street and from Greenwich street into Christopher street, where the tubes have been constructed accurately to the curvature required by the use of taper rings made so that the increased distance measured around the external line of the curve corresponds to that of the curvature required.

The segments of plate lining were put in place by the erector with the use of an erecting lug cast in the center of each plate so that the grip of the erector could pick up and balance a plate in order to put it in place. The use of the lug was found to be more convenient and safer in operation than special types of attachments, with which experiments were made.

Considerable difficulty was experienced in all shield-driven tunnels by the rotation of the shields. This occurs notwithstanding all precautions and seems to be attributable to conditions entirely outside of any personal control. The rotation caused little difficulty up to a certain point; after that, definite measures had to be taken to correct the rotating tendencies so the shields would actually be brought back to their normal position, and this was done with complete success.

The tunnels under the streets of New York City, both uptown from the river front to Twelth street and Sixth avenue, and downtown under Cortlandt and Fulton streets, are throughout in formations of sand and gravel of varying character and quality, some of the material being simply New York quicksand. Rock in all these cases lies very near to the grade of the tunnel, and consequently in all this work it comes up irregularly in peaks in front of the tunnel location, thereby necessitating the execution of most of this work with the previous preparation for finding rock foundation with sand and other loose material overlying. The same condition applies equally to the work carried on in New Jersey, where the micaceous gneiss rock underlying the Pennsylvania station disappears below the grade of the tunnels at approximately the Newark line junction on Washington street and going north along Washington street, and while the lower level tunnel continues a considerable distance in rock formation the higher level tunnel goes out of rock into sand and hardpan formation, which yields quantities of water. A short distance south of Pavonia avenue, Jersey City, the gneiss rock disappears, and when rock is again encountered north of that point it occurs as the red sandstone of the Newark formation. Overlying this rock bed throughout is wet sand and boulder formation. In consequence of these several formations tunnel construction had to be carried on partially in rock and partially in loose ground throughout. The added condition of being below tide level and all the soil being



Shield in Soft Material Overlying Rock.

saturated with water also necessitated carrying on all the work under air pressure.

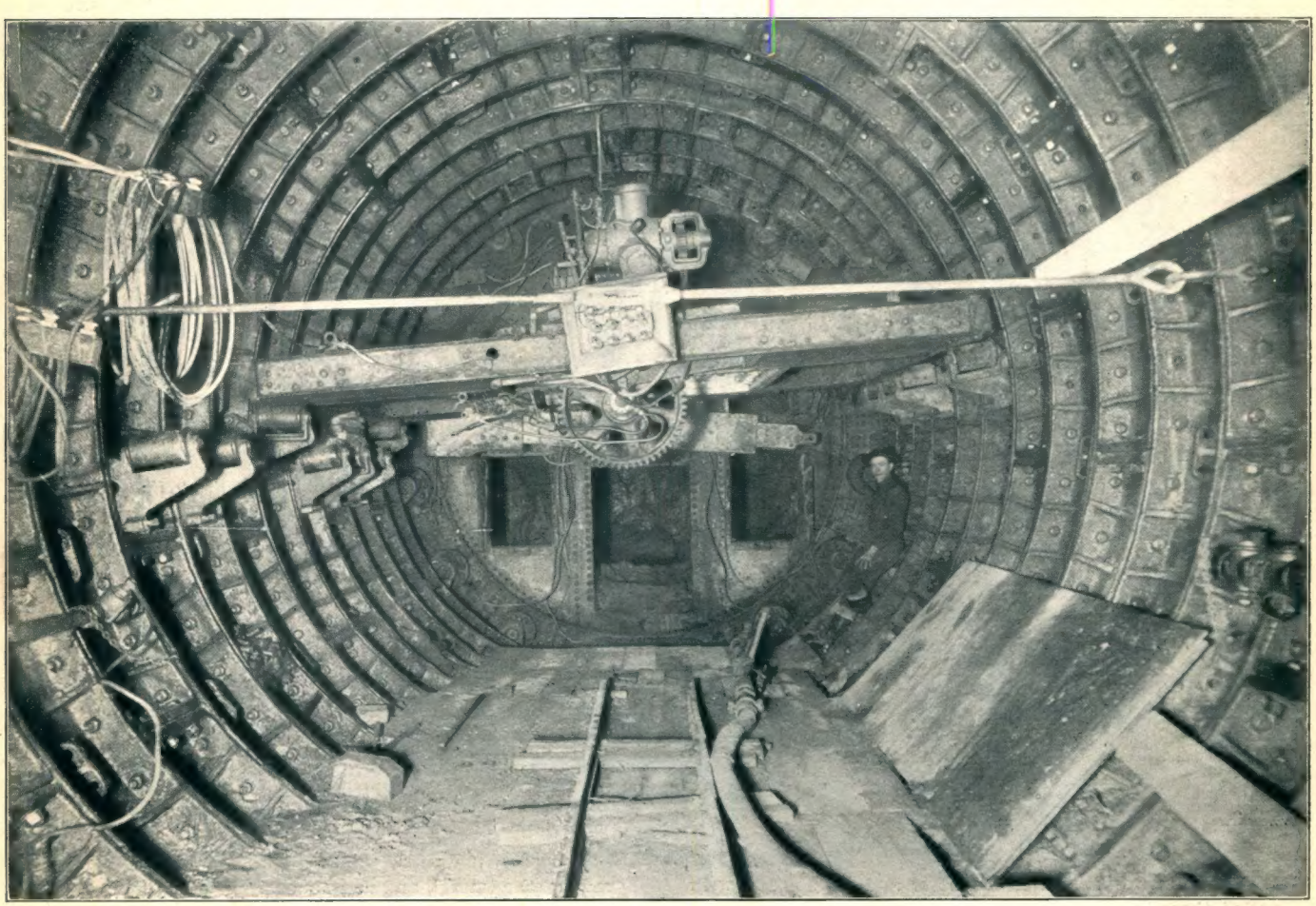
In all cases where the tunnels were started from shafts or chambers entirely in soft ground, shields were installed, even though the work necessitated blasting rock at later dates, but in the cases where work commenced in solid rock and passed from that into other material, the ordinary methods of soft ground mining were utilized.

In the river sections, where the tunnels were invariably constructed with shields, the iron tube lining has been used, but wherever the tunnels were constructed by mining methods the internal lining was completed in concrete.

In all cases of construction in tube tunnel with a shield, excepting where the material is pure clay, it is essential to remove the material in advance of the shoving of the shield, as it is an absolute impossibility to shove the shield into any other ground than clay without most serious injury to the structure of the machine.

In carrying out the shield tunnel work with rock bottom and soft ground overlying, the greatest possible difficulties have been encountered throughout. In work of this character it is always necessary to support the top before the removal of rock, and consequently the soft ground overlying the rock for the length of a tunnel ring has to be cleaned out completely and the breast and roof supported by secure timbering before the rock can be attacked. In almost all these cases the material is very porous and allows the passage of enormous quantities of air; consequently, the exposed breast has to be carefully puddled with clay in putting the breast boards in place, and all cracks in the breast boarding also have to be plastered with clay in order to hold the air pressure. In addition to this, the tail of the shield has to be carefully packed to reduce the loss of air between the finished lining and the tail section of the shield. Having the soft ground breast carefully secured, the lower portion of rock has to be drilled and blasted as in ordinary rock operation, and as the charge of powder which can be used in the face of the shield, with the timbering overhead, is extremely limited, the work becomes tedious, difficult and dangerous. This was particularly so in numerous cases where the rock ran along just at the roof line, so that there was practically a full face of rock with soft ground occurring immediately at the roof of the shield. This made the breasting and timbering of the overlying soil unusually difficult and hazardous.

It is interesting to note in this connection that in driving the shield for the westbound tunnel, forming the uptown approach from the Hudson river, under Christopher street to Twelfth street and Sixth avenue, the shield traveled and constructed 4,525 ft. of iron-lined tube tunnel, of which distance 2,075 ft. was in partial rock formation. In this work there were exploded in front of the shield itself 26,000 sticks of dynamite without disturbing the surface of the streets or buildings immediately above.

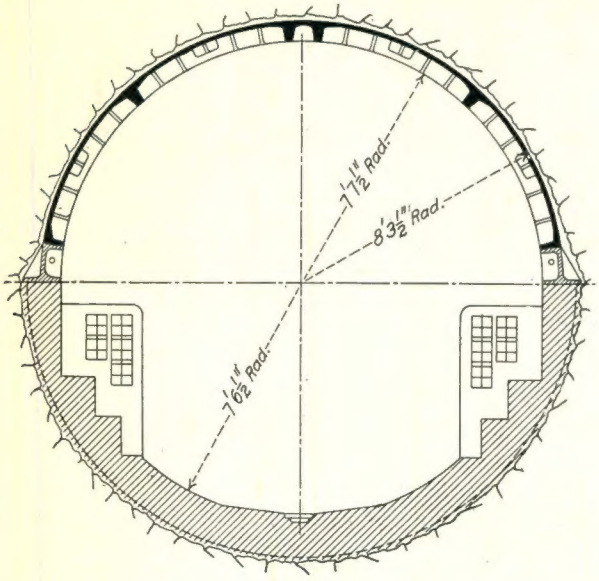


Rear View of Shield.

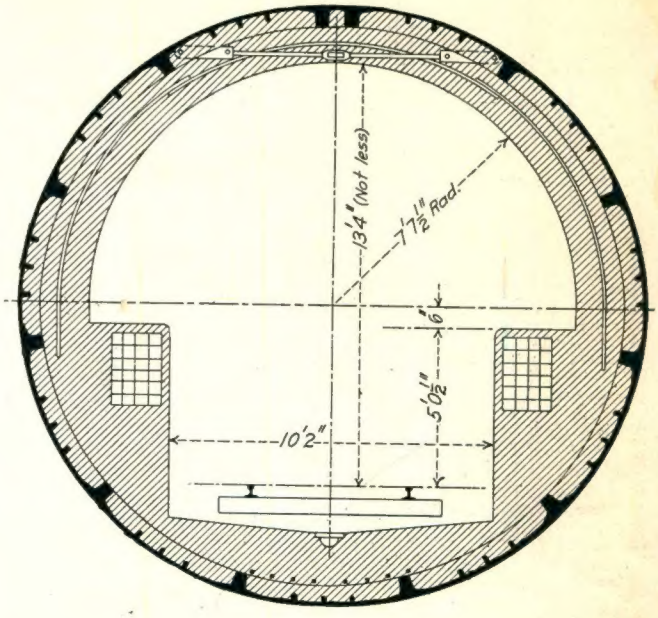
In the removal of rock partly in solid cross section but very largely in headings of this character, the company used 350 tons of dynamite. In the tunnels where underground mining methods were installed, the work was carried on with air pressure precisely as in the shield tunnels, but two side headings were driven at an elevation to permit of putting in wall plates in advance of any enlargement. The roof was supported by steel I-beam sets, consisting of light section 8-in. I-beams cut with the proper bevels for the section sets, con-

nected by plate straps at the butts and spaced about 4 ft. apart. The lagging was executed in the ordinary manner with wood planking and any cavities carefully packed and the entire lagging plastered with mud. The fact that work was carried on in the river tunnels in the Hudson river silt at the same time work on these tunnels was being executed enabled the very finest quality of clay for plastering to be obtained economically, and a considerable amount of clay coming out of the river tunnel was, therefore, transferred to other points where soft ground mining was in progress, for the purpose of plastering. In lining these tunnels with concrete the concrete used was usually composed of one part cement, 2½ parts sand and five parts broken stone. The side walls were first constructed and the arch was usually built with a traveling arch frame, which was a light structure of steel plated with steel plates, running on wheels on a track.

In Jersey City and Hoboken, where the various tunnels of the several routes make connections between Jersey City, Hoboken and uptown New York, the elimination of grade crossings was essential to the design of the work, and, as before stated, the tunnels were superimposed for this purpose. This operation necessitated the construction of junctions in

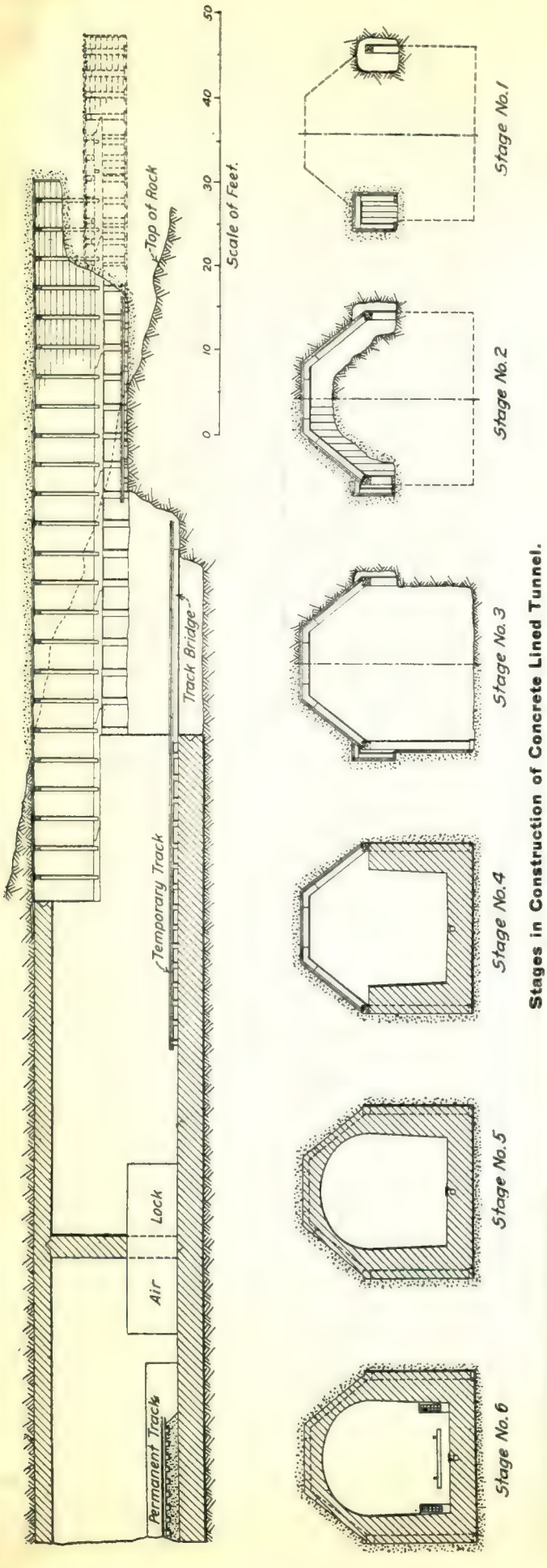


Tunnel with Cast Iron Roof Lining.



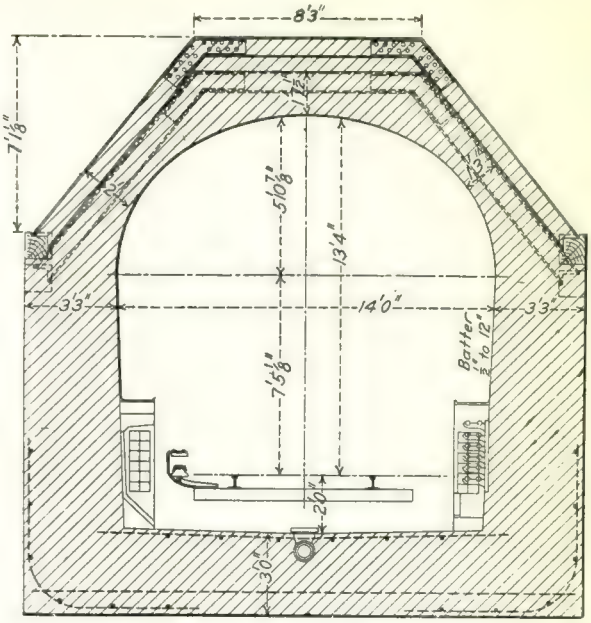
North Tunnel as Lined with Concrete.

Shield Entering Caisson No. 3.

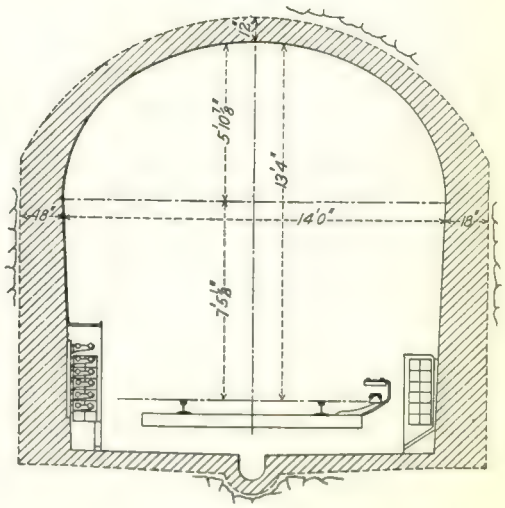


Stages in Construction of Concrete Lined Tunnel.

the tunnels, all of which, unfortunately, came at locations where the construction would be in loose sand or other soft formation in which grave difficulties would have been involved in making the enlargements entirely by underground methods. The enlargement at the junction of Sixth avenue and Ninth street was carried out entirely by underground methods, on account of the conditions of traffic on the streets above, which would have made open-cut methods very difficult and have caused great inconvenience to the public. This junction was constructed in sand formation overlying the rock, and as the location was in part on the site of the former Minetta creek



Concrete Tunnel in Soft Ground.

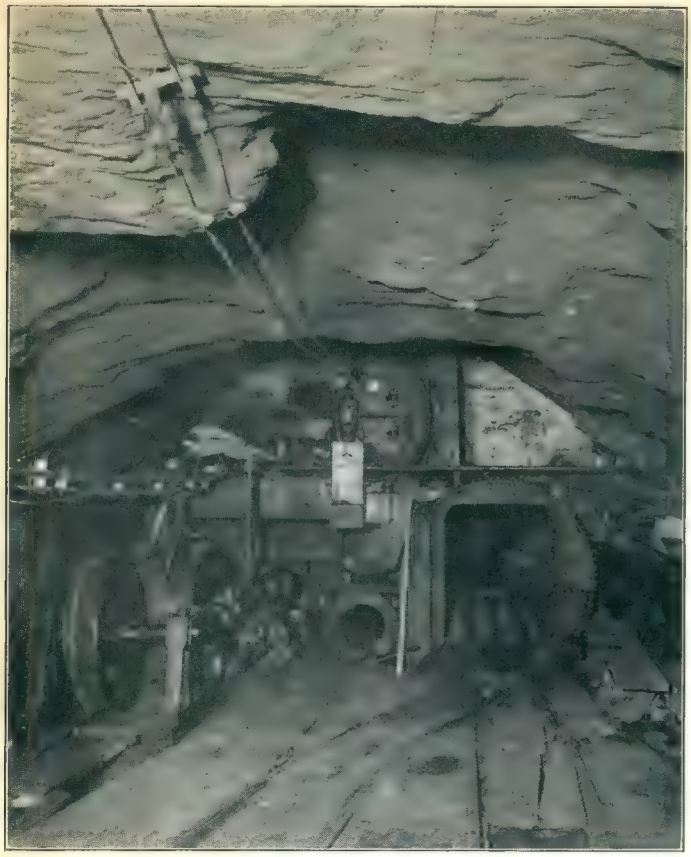


Concrete Tunnel in Rock Formation.

there was a good deal of quicksand present to be taken care of. The entire work was therefore executed under air pressure. At this point the shields in the two diverging lines were carried through continuously, forming the external lines of the enlargement, and these tubes so constructed were used to brace from in constructing the enlargement. Sections of lining plates were taken out from the sides of these tubes and tunneling carried on between the tubes for the insertion of the heavy timbering put in place to carry the roof, maintaining the breast throughout and carrying the work on in section lengths. In this way excavation was carried on and the arch forming the

Old Piles Encountered in Soft Ground Work.

Tunnel Work in Soft Ground.



Air Lock.

permanent lining put in place in short section lengths but of the full structure width, having in part a clear span of 60 ft. This work was executed with only a very slight settlement of the surface of the ground. At the same time the columns of the elevated railway structure overhead were supported by long girders wedged to brackets riveted to the columns and constantly watched to take up any settlement which might occur. This method of underground enlargement was necessarily very expensive, and to execute similar work in the three different sites on the New Jersey side, each of which was of greater dimensions than the enlargement at Sixth avenue and Ninth street, made a careful detail study of the possibilities desirable.

In Jersey City, fortunately, the three junction enlargements involved came below properties occupied by the Delaware, Lackawanna & Western Railroad and the Erie Railroad for yard purposes, and by arrangement with those companies the surface of the ground was occupied for the purpose of carrying on the work therefrom. In all these cases the enlargement foundation could be carried down to rock.

It was decided to make these enlargements by caissons sunk from the surface, and the caissons were in the first instance designed of structural steel to be internally lined with concrete, but owing to the difficulty in getting these constructed in any reasonable time and to the very high prices demanded by the steel manufacturers for such construction, the situation was restudied, with the result that a plan was worked out for reinforced concrete caissons, which permitted the work to be started at once without the delay due to waiting for steel construction, and the work could also be much more cheaply executed. These caissons were therefore built on the surface of the ground with the tunnel section forming the air chamber, the invert being omitted until the caisson had sunk to its final position and equipped with air locks and other necessary arrangements for sinking, and the three caissons were sunk entirely from the surface in every way as though sinking a bridge pier. These caissons were internally of the same shape as the tunnels, and were sunk to the necessary grade of the tunnel constructions and backfilling on top, this backfilling, however, being carried on as the caissons were sunk so as to add effective weight in the sinking operation.

In sinking these caissons, various obstructions were found and had to be removed. At Caisson No. 1, which is located nearest to the river, a canal boat was found at a considerable depth below the surface and had to be completely cut up into small sections and removed through the air locks.

The openings in the caissons at the points where the tunnel tubes were to enter were constructed with dummy drum heads of concrete, jointed so that they could be readily cut away. As soon as the caissons reached the final elevation those drum heads through which the tunnels were to be constructed were cut out and shields erected for the commencement of tunnel construction from the caissons. In other cases, the shields driven from other points were aligned so as to come to the points where the drum heads were installed in the caissons, and in every case these were very carefully brought together and the joints sealed with the tunnel lining before the drum heads were cut out.

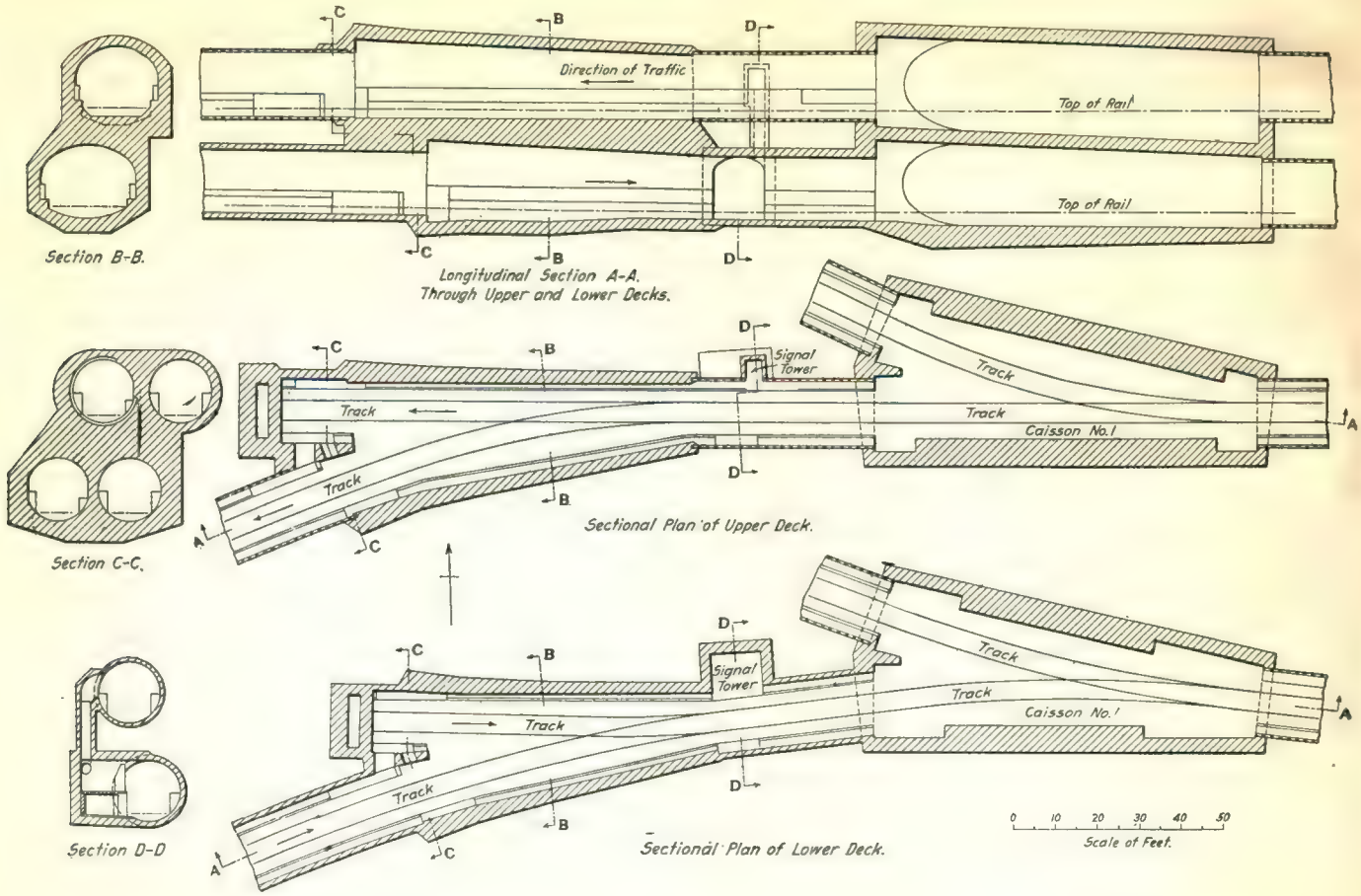
Caisson No. 1. The main outside dimensions of this caisson are as follows:

Length	101 ft. 2 in.
Width	23 ft. 5¼ in. to 45 " 8 "
Height	51 " 0 "

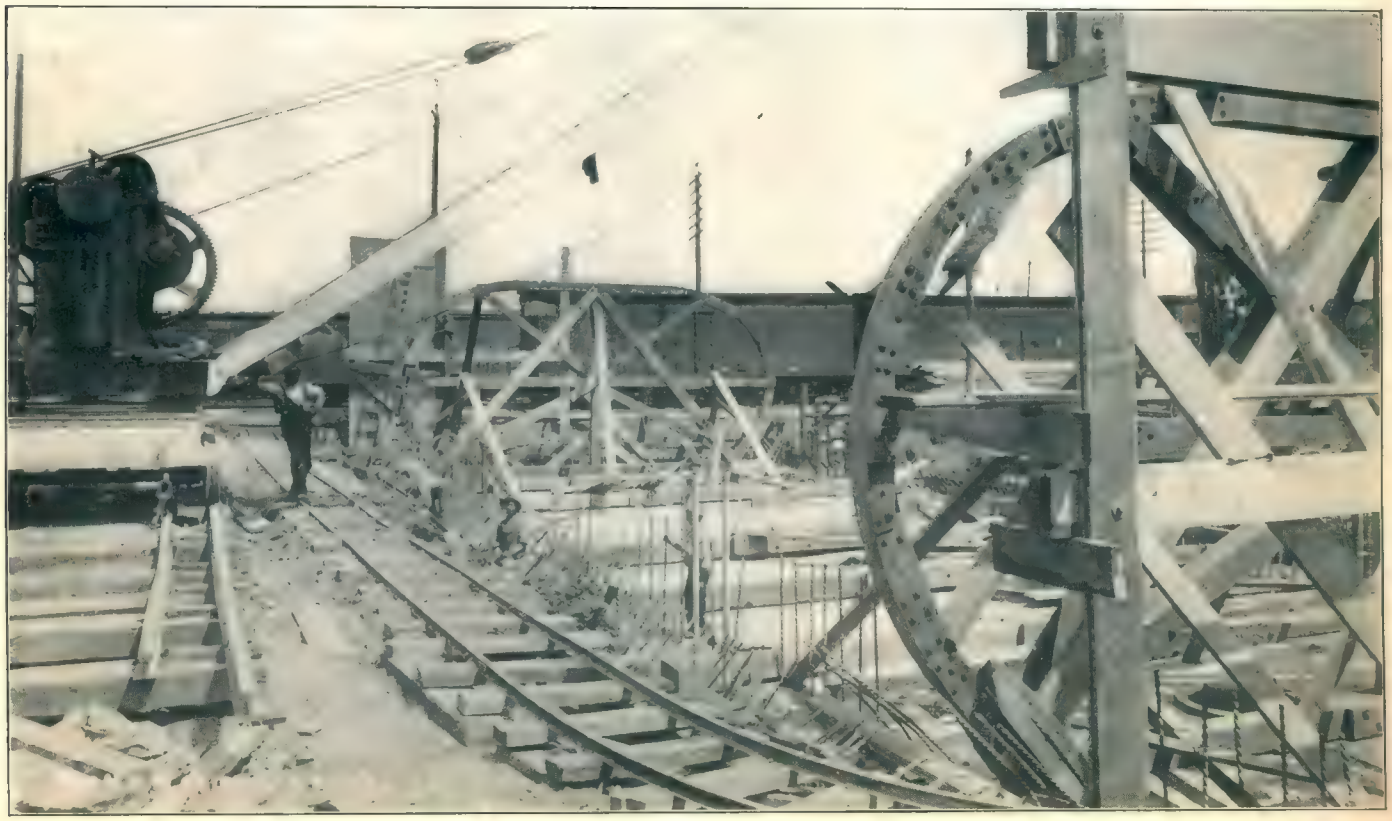
This caisson tapers so as to receive the two river tunnels superimposed at the narrow end, and at the wide end two tunnels superimposed to and from Hoboken and two tunnels superimposed to and from the Erie Railroad station, Jersey City.

Caisson No. 2. The principal outside dimensions of this caisson are practically the same as those of Caisson No. 1. At the narrow end of this caisson are two tunnels superimposed to and from Hoboken, and at the wide end there are two tunnels superimposed to and from Jersey City and two tunnels superimposed to and from uptown New York.

Caissons at Junction of Jersey City and Hoboken Lines.



Caisson No. 1.



Forms for Upper Deck of Caisson No. 3.

Caisson No. 3. The main outside dimensions of this caisson are as follows:

Length	106 ft. 5 in.
Width	45 " 0 "
Height	43 " 11½ "

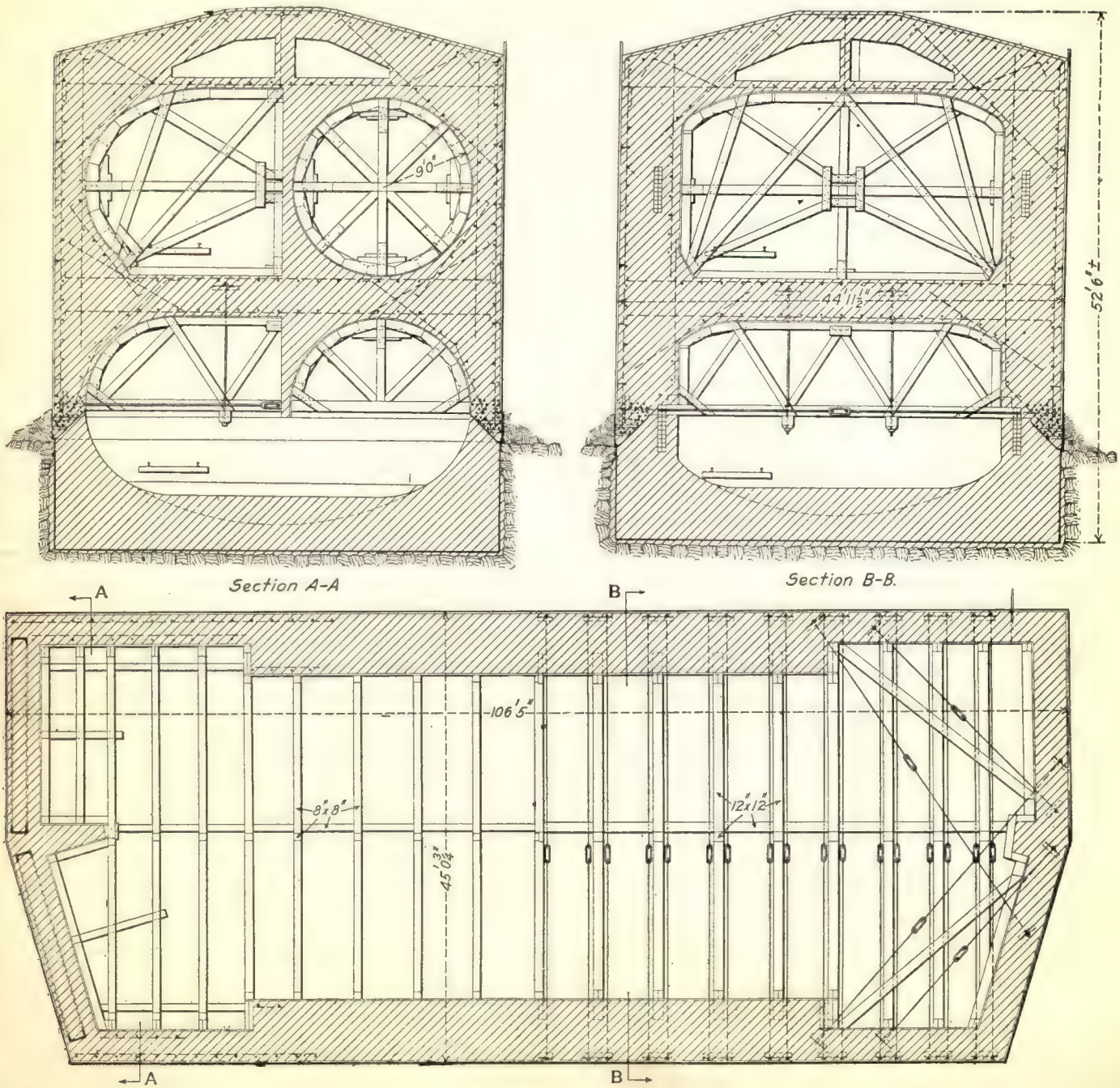
This caisson was arranged with eight tunnels, as follows:

At the north end, two superimposed tunnels to and from Hoboken and two superimposed tunnels to and from New York, and on the south end two superimposed tunnels to and from Jersey City and two superimposed tunnels to be used in the future when a physical connection is made with the tracks of the Erie Railroad.

STATIONS.

The stations along the lines of the tunnels involve very diverse conditions, and each one, apart from the group of stations on the Sixth avenue extension from Fourteenth street to Twenty-third street, inclusive, required separate studies to meet the varying conditions. The controlling questions in considering the subject of stations have been governed in a large measure by the franchise rights in the city of New York and the interchange of business with the railways in New Jersey. In New York City the franchise throughout required that these tunnels, excepting on Sixth avenue, should be constructed at such depths as to permit any future municipal subways being constructed on intersecting streets at a level above the same. This applied to the downtown terminal as well as to the uptown lines, and necessitated the construction of the tubes, and in large measure also the stations, with no part of the construction nearer the surface than some 20 ft.

Christopher street station.—This station was considered to serve only a limited volume of transportation; that is to say, the interchange with the Ninth avenue elevated line and the trolley lines at that point, there being comparatively little business originating in that neighborhood which would accrue to the tunnels. In consequence of this a station at that point of any magnitude was not necessary and the very narrow width of Christopher street also precluded the construction of a large station. In this case, the two tunnel shields, driven



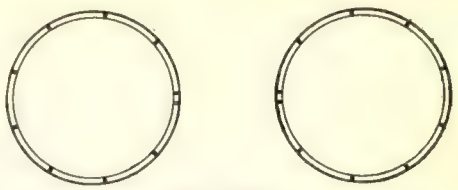
Construction of Caisson No. 3.

side by side, was set as far apart as the width of Christopher street would permit and the shields were driven continuously through the length laid out for the station. At the same time the lining was installed with the key segment put in place at the horizontal side axis and in each tunnel the key was placed nearest to the adjacent tunnel; that is to say, the lines of the keys faced each other. After the tunnel had been driven through to a point beyond the length of the station some of the side plates were taken out of each tunnel and a roof shield installed running on the external surface of the finished tubes and with this roof shield there was constructed a central arch springing off the lining of the two adjacent tunnels. As the roof shield was advanced and the lining for the roof was put in place, the sides were taken out and steel girders run longitudinally carrying the abutting arches so as to take the vertical loads and a concrete arch was also placed in the invert, between the girders, taking the thrust at the bottom. As the side plates of the two adjacent tunnels were removed, a series of columns supporting the top and bottom girders were installed, these columns in turn carrying the loads of the arches. The whole of this work was executed under air pressure and the construction of this station provided a satisfactory and capacious structure and involved no disturbance to the street surface, and, therefore, a similar method was adopted for the construction of the station under Christopher street at the intersection of Greenwich avenue, which is now known as Ninth street station, the only change in the construction of this station being, that in place of using the roof shield, ordinary mining methods were employed and the center arch of the island platform was constructed of reinforced concrete. This was adopted on account of the difficulty experienced in water-proofing the arch of the Christopher street station, due to the fact that the water found its way through the joints between the steel girders and concrete butting against the girders, and the construction of the center arch at Ninth street station enabled a monolithic construction to be carried out with very satisfactory results. In both of these cases the type of construction enabled the station to be built without carrying the head room occupied appreciably higher than the lining of the tunnel itself, and, consequently, enabled the tunnels to be brought as near to the surface of the street as the conditions of the franchise permitted.

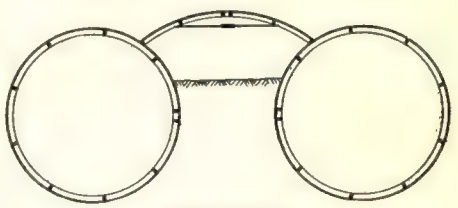
At the Christopher street station the entrance is through the private property of the company, upon which is constructed a sub-station for the transformation of power for operation of the railway, and at Ninth street station the entrance is from private property of the company at the corner of Ninth street and Sixth avenue.

The stations on Sixth avenue were all constructed by the usual open cut methods, and in every case the construction was as near the surface of the street as the grades would permit and, excepting for the arrangement of the show windows on the platforms of the stations giving facilities to the adjacent business properties for the display of their wares, there is nothing unusual in the construction of these stations, excepting that the arch form of roof construction was carried out in every case.

Hoboken terminal.—This station is beneath the property of the Public Service Corporation and during the construction of the station it was necessary to maintain uninterruptedly the trolley car tracks of that company above the station. The car repair shop of the Hudson & Manhattan was to be situated on the surface of a portion of this land leased from the Public Service Corporation at the extreme westerly end of this property at the corner of Hudson place and Hudson street, and to get access to the tunnels for cars it was necessary to install a car elevator 60 ft. long from the tunnels below to the ground floor of the repair shop, and this had to be taken into consideration in the design of the station. There was only sufficient space available to design this station for two operating tracks with a central loading platform and two external unloading platforms, and, in addition, to put in a third track for car repairs and inspection purposes. This third track is constructed over a pit and the rails are carried on pedestals, which enables a man to stand erect underneath the motors of the cars. The location of this station gives close connection at the extreme easterly end to the station of the D., L. & W., and by stairways at about the center of the platforms for interchange of passengers with the trolley terminus of the Public Service Corporation. The work of construction of this station was carried on entirely in the open. The side retaining walls were constructed in trenches, sheathed and thoroughly braced, and the columns also were put in place in holes dug for the same, and as the work of excavation of the columns and sidewalls proceeded the main excavation was carried out in benches and the bracing carried across. As there was direct water pressure on the outside of the foundations and sidewalls throughout, the invert construction of this station was made in precisely the same way as the roof, by groined arches transmitting the loads



Stage No. 1.



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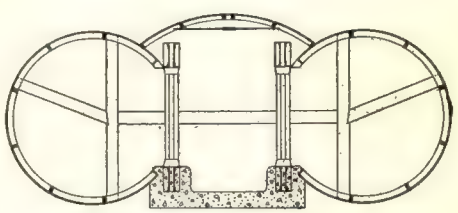

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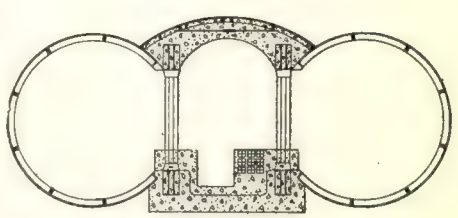

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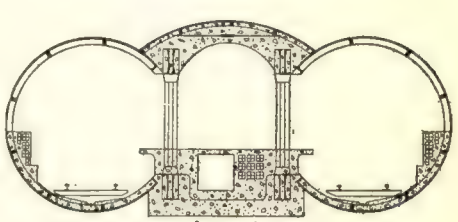


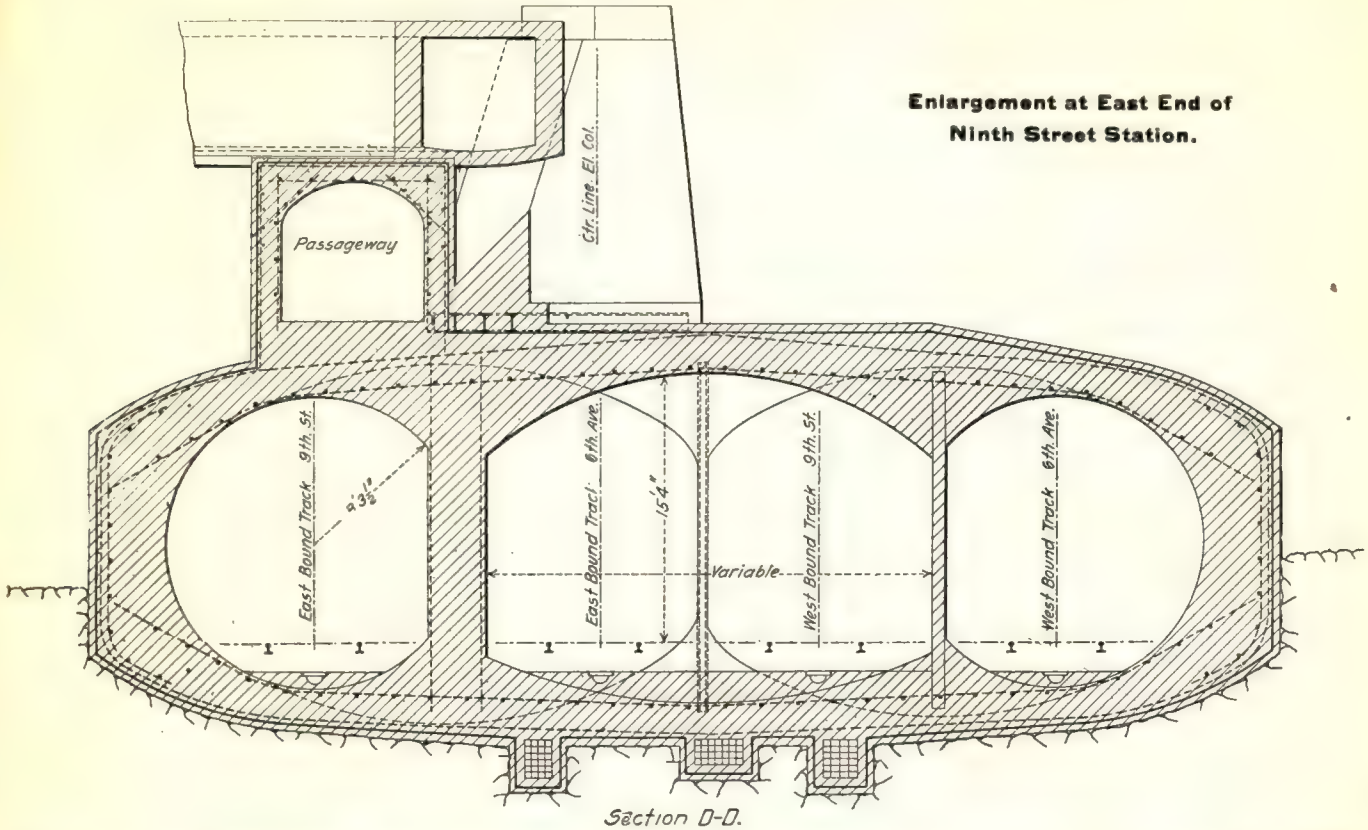
Stage No. 5.

Christopher St. Station.

Construction.

to the columns, and the invert construction was waterproofed throughout with fabric and pitch. This waterproofing was carried right up over the sidewalls and roof so as to enclose the entire structure in a waterproofing envelope. The arrangement of inverted arches also gave the strength necessary to avoid a very heavy slab of base concrete which would otherwise have been necessary to resist the pressure. The tracks were placed deep enough to permit of the construction of a distributing concourse immediately above the tracks for the proper distribution and sorting of passengers to and from the street and trolley cars, and the ticket offices, chopping boxes and barriers were placed on this floor. The entire arch construction both in the roof and the invert, as well as the sidewalls, is reinforced with twisted rods of high carbon steel. The car elevator installed operates from the track level to the surface into the enclosed portion of the property equipped as a repair shop. This shop has a small but modern and compact outfit of machinery necessary for carrying on efficient car repairs.

Erie station.—The layout of this station must be considered largely in the light of an arrangement made for use pending the reconstruction by the Erie Railroad of its terminus, at

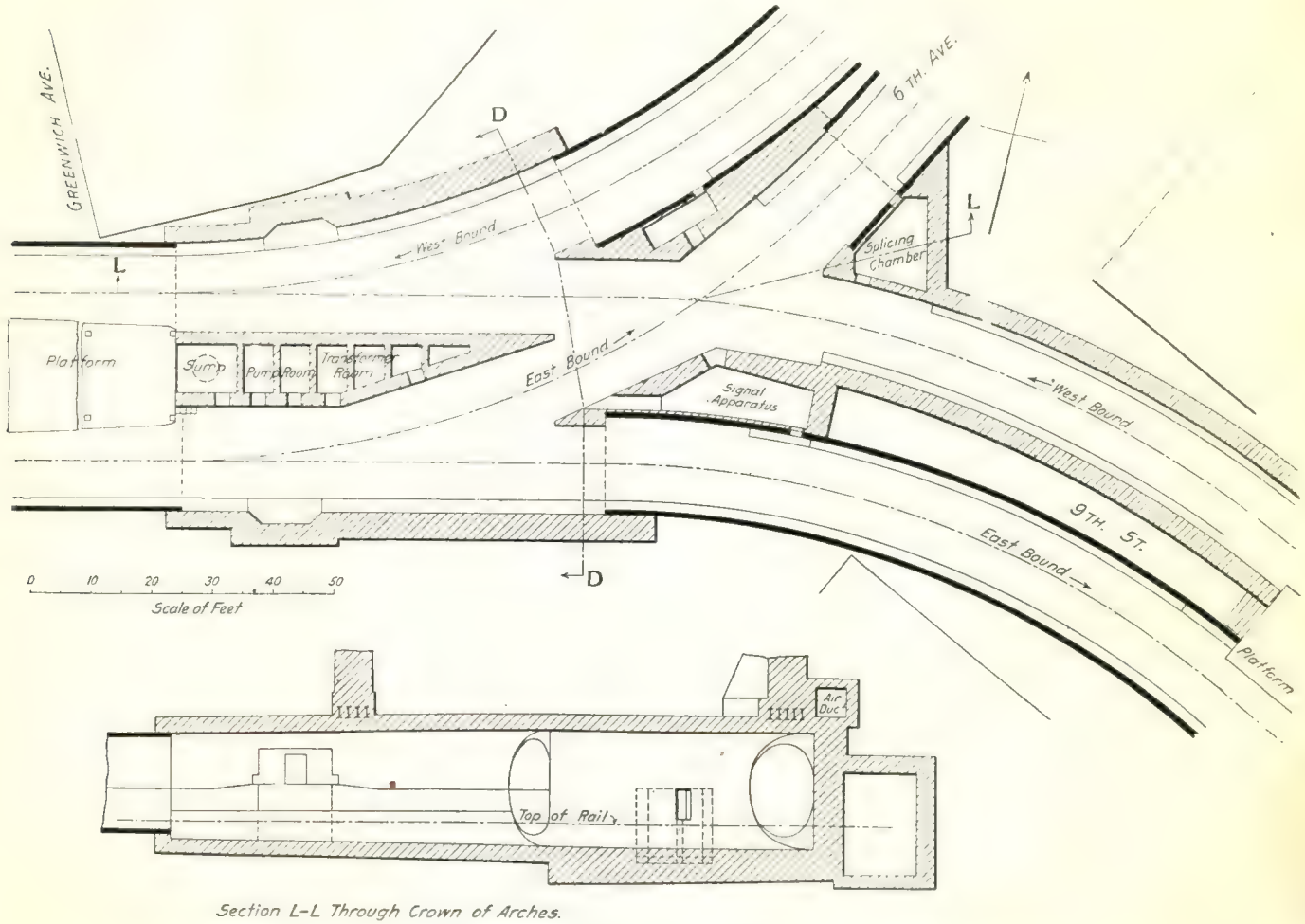


Enlargement at East End of Ninth Street Station.

Finished Concrete Roof of Station.

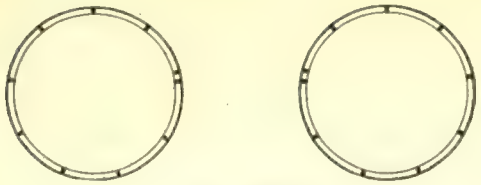
which time physical connection will be made between the Erie tracks and the tunnel tracks for service through to uptown and downtown New York. The line of the tunnel, which was fixed by outside conditions, both at Hoboken and at the Pennsylvania Railroad in Jersey City, if continued straight between these two fixed points would have located the tunnels a considerable distance from the platforms of the Erie station, and in order to bring the underground station of the tunnels as near as possible to the Erie platforms, the line of the tunnels between the two points mentioned was deflected considerably eastward. The Erie has constructed an underground waiting room with stairways in the centre leading to their train platforms on the surface, and from this waiting room a passageway, 15 ft. in width, has been constructed on a descending grade to the underground station of the tunnels on Pavonia avenue near Kelso street, Jersey City. This passage provides a distance from the center of the Erie train platforms to the platform of the underground station shorter than the distance from the center of the Erie platforms to the shore end of the Erie ferry boat on either the Chambers street or Twenty-third street line, and materially shorter than the distance if measured from the outer end of the ferryboats. At the same time, the narrow passageway gives the impression of greater length. This passageway was constructed in open cut of reinforced concrete throughout, and the portion of the passageway over which there will be railway tracks is constructed on pile foundations.

The underground station was built in the same manner as the station at Ninth street and Sixth avenue, New York, by continuing the tunnels through the length of the station in the first instance and later constructing an arch between the tubes and transferring the vertical loads to two rows of columns, and with reinforced concrete construction both for the roof and the invert. The foundations in this case are solid sandstone, although the roof throughout is in loose sand and gravel formation. The connection for Erie Railroad passengers as well as those from the street is at the extreme northerly end of the station by a stairway, 12 ft. wide, and the island platform of the station is 18 ft. wide. In addition to the connection for Erie Railroad passengers, there is provided at this point a stairway and also elevator accommodation for passengers to and from the street on Pavonia avenue. The elevator installation consists of two cars each 10 ft. square with a capacity of 50 persons, and the rise is 31 ft. from floor to floor. The elevators are of the electric traction, Marine Engine & Machine Company's type, fitted with pneumatic door operating devices of the Burdette-Rowntree Manufacturing Co.

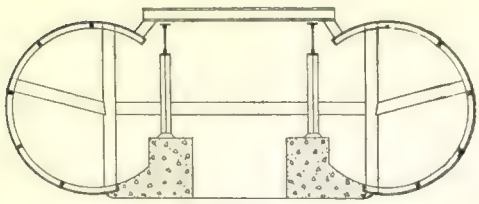


East End of Ninth Street Station.

Pennsylvania station, Jersey City.—Fortunately for the construction of the Pennsylvania station, the location adopted put the station in solid rock formation. The station itself consists of two main arches, one for eastbound and one for westbound, each having a span of 23 ft. 6 in. clear. The platform in each arch is 12 ft. wide and the length is 387 ft. The elevators to handle passengers to and from the Pennsylvania Railroad above are located at the extreme easterly end of the station, and the elevators to handle passengers to and from the street and trolley cars at Exchange place are located approximately at the westerly end of the station. The four elevators to the Pennsylvania trainshed were necessarily located in respect to the passenger barriers in the Pennsylvania lobby, and the number and size of the elevators were determined essentially by the construction paneling of the Pennsylvania trainshed and the space which could be spared by the Pennsylvania Railroad



Stage No. 1.



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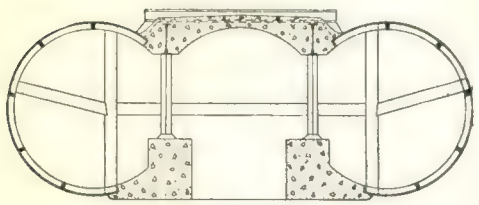

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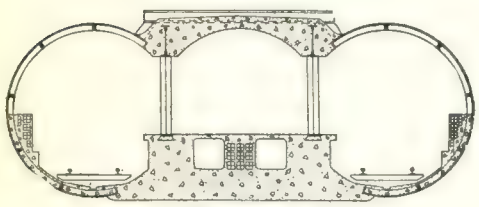
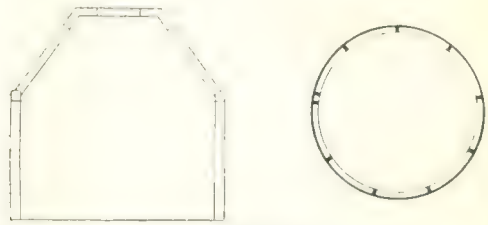


Stage No. 4.

9th. Street Station.

Construction.

for the operation of this service. This permitted the installation of four elevators, each having a floor dimension of 10 ft. x 10 ft., and each accommodating 50 passengers. The entire shaft in which these elevators operate was put down as a single shaft 50 ft. x 10 ft. inside dimensions, and divided into four bays by cross bracing. The location of this shaft necessitated its being put down in water below the ferry roadway deck of the Pennsylvania terminus; underlying the water is soft dock mud overlying the rock. The shaft was constructed by driving steel sheet piling outside and bracing internally as the excavation was taken down. When the excavation got nearly down to the rock level the external pressures buckled one corner on the rock and caused a blowout with considerable distortion of the steel sheet piling which caused the work to be suspended entirely for a while. It was then found necessary to put an air floor into this shaft and to install air pressure to get it down, which involved considerable difficulty as the air floor and internal lining had to be built on false work. With the use of air pressure the excavation was completed to bedrock, and the portion of the steel sheet piling which had buckled cut away, and the rock drilled and blasted away to get a secure bond for the upper shaft construction. The concrete internal lining of the shaft was then carried up from bedrock to above tide level. The rock excavation of the shaft was driven up from below, all the work until completion being carried on under air pressure to insure safety and security in construction. The reinforced concrete shaft was carried up continuously as a monolith to the top of the head house now existing, but the outside of the concrete shaft was afterwards furred and covered over with a steel framework with staff and plaster to coincide with the architectural arrangements of the Pennsylvania lobby. Passages in the underground station were constructed to permit of the entrance of passengers from Pennsylvania Railroad trains on one side of the elevators at the top of the shaft, and to leave the elevators on the opposite side at the bottom, and similarly to permit passengers from the tunnels for Pennsylvania Railroad trains to enter the elevators at the bottom of the shaft on one side and to leave at the top of the shaft at the other side, these arrangements obviating entirely any conflict of traffic. The elevators at this shaft make a trip up and down in 2 minutes; that is to say, with the four elevators, one is loaded every 30 seconds, which is equivalent to a movement of 6,000 persons per hour in each direction. The pumping plant operating the entire elevator service at this point and at Exchange place consists of Standard Plunger Elevator Company's electrically driven express pumps operating under a pressure of 190 lbs. per square in., and C. & C. motors controlled by the improved Cutler-



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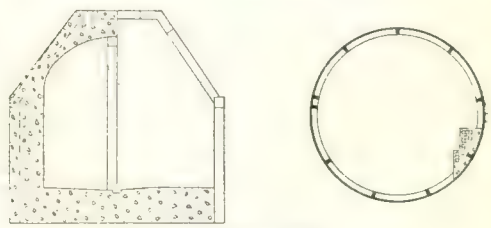

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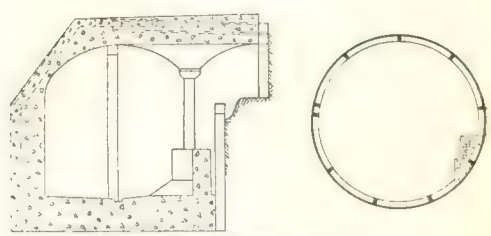

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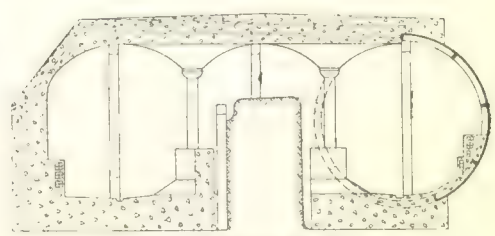

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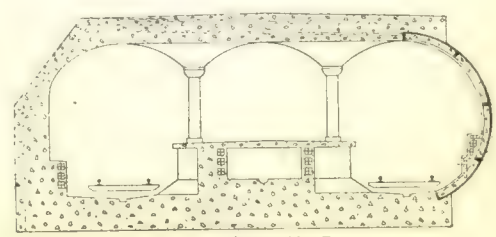


Stage No. 5.

Erie Station.

Construction.

Hammer type of automatic rheostat control. The rise of the four elevators to the Pennsylvania Railroad trainshed is 92 ft. from the station floor to the Pennsylvania Railroad train deck floor.

The elevators to the street at Exchange place consist of two cars, each 10 ft. x 10 ft., with a capacity of 50 persons each; rise, 63 ft. The six elevators (four at Ferry roadway and two at Exchange Place) are of the plunger type, furnished and installed by the Standard Plunger Elevator Company, and are fitted with pneumatic door operating devices of the Burdett-Rowntree Manufacturing Company's make.

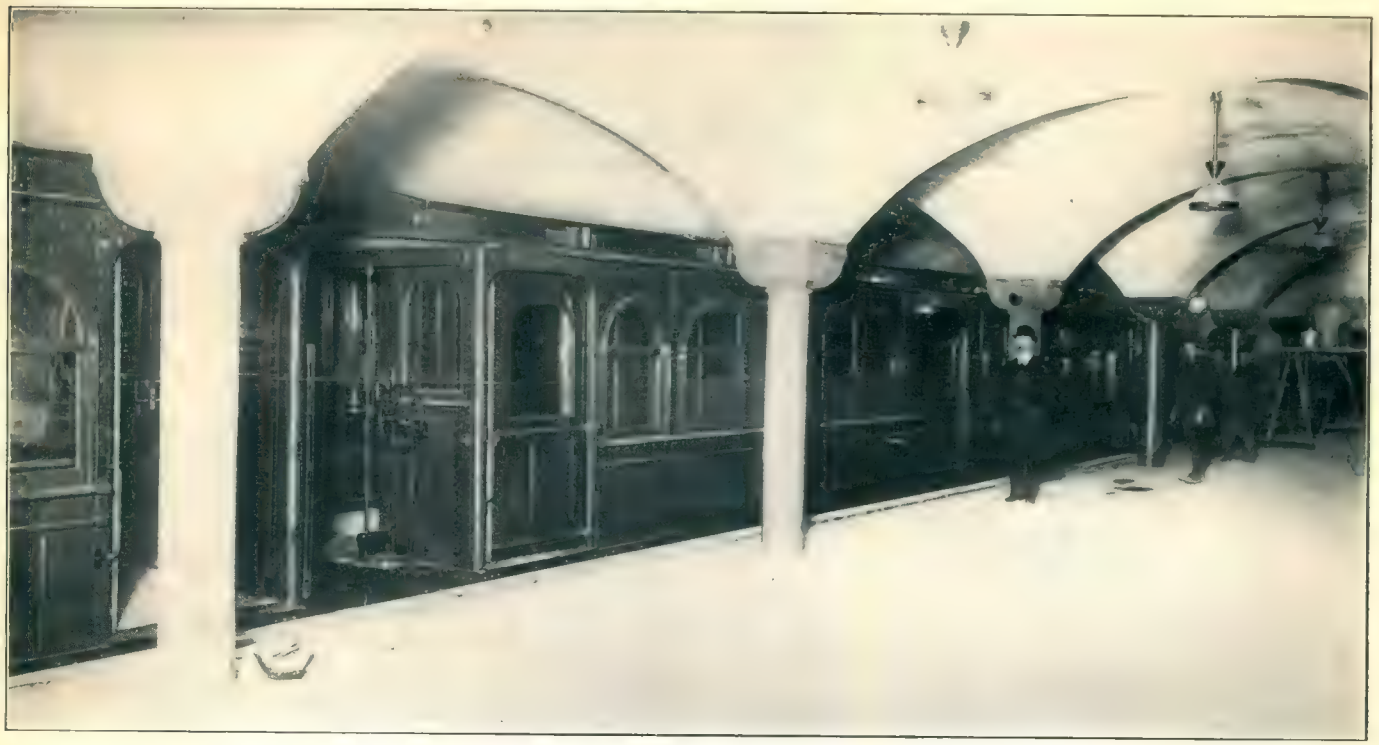
The construction of the elevator shaft at Exchange Place proved to be a very difficult piece of work, due to the land through which the shaft passes having been reclaimed by filling with immense trap rock boulders which apparently had come from the Point of Rocks cut in Jersey City. This shaft was put down with steel sheet piling, but great difficulty was experienced by the buckling up and injury to this sheet piling by contact with the boulders, and it was only by the installation of exceedingly large pumping units and excavating ahead of the sheet piling that the shaft was ultimately sunk to rock. A stairway, which is purely for emergency use, winds around

Erie Station.

the outside of the elevators, giving access to and from the underground station. This stairway is 5 ft. wide.

Church Street Terminal.—The downtown terminal involved one of the most complex and difficult engineering propositions ever attempted. The enormous value of the necessary real estate on which to construct a station suitable for the downtown business made it essential that such property should be put to uses other than simply the construction of a station underground in order to insure an income from such property commensurate with its great value. Borings made all over the downtown district indicated very plainly that wherever such a station was located the underground construction would be largely in quicksand formation. The location finally adopted is that bounded by Church street on the east, Cortlandt street on the south, Fulton street on the north and private property fronting on Greenwich street on the west. This location permitted of the construction of the station north to south, and allows a train of eight cars to stand in the station practically on a tangent, entering the station at the Cortlandt street end and departing at the Fulton street end, thus obviating the construction of a stub end terminal. This property was acquired partly by purchase and partly under condemnation proceedings. The provisions of the franchise placed the tracks at such an elevation that depth was provided at Greenwich street for a subway which might be constructed in the future above the tunnels of this company; that is to say, the elevations laid out for the tracks of the Hudson & Manhattan were approximately 40 ft. below the surface of the street. This depth made it essential that the waiting room should be on a floor above the tracks, which left a complete floor at the street surface elevation available for the construction and uses of an office building above. The buildings had to be constructed in every respect subordinate to the prime necessities of the railway station and railway operation. The station was planned with the view that at a future date there will be two additional tubes crossing the Hudson river from this downtown terminal direct to the Erie Railroad, at which time there would be two double track railways terminating at this station, and all platforms, stairways, entrances and exits were designed for handling the ultimate maximum capacity of the two double track railways. To obtain any such results it was obvious that the loading platforms and the unloading platforms for the tunnel trains should be separated, and that the stairways giving access to the loading platforms, and the stairways providing egress from the unloading platforms should be staggered in such way that the movement of passengers to and from the trains would not conflict in any manner on the waiting room floor. This arrangement has been carried out, as may be noted on the plan. The concourse, or waiting room, floor was essential to the operation of the railway station. The track floor could not be occupied by anything whatever other than the tracks and platforms, and as the electrical department required for the operation of the railway a transformer sub-station at this terminal, and it was also necessary to install a large layout of machinery required for the operation of the buildings above, additional floors necessarily had to be built below the track level. This enormous depth of excavation over the entire area covered by the stations and buildings necessitated the construction of a dam wall around and enclosing the entire area from the north side of Fulton street to the south side of Cortlandt street, and this dam had to be absolutely watertight and carried to bedrock and securely sealed thereto. The work of enclosing the portion of the station approaches under Cortlandt and Fulton streets, it was considered, would be desirable to execute separately from the main building foundation and coffer dam, owing to the fact that under these streets it was not necessary to carry the foundation and enclosure below the track level. Caissons 8 ft. wide and approximately 30 ft. long were sunk, abutting one against the other, around the external line of the property and approximately on the south line of Fulton street and north line of Cortlandt street. Forming this main coffer dam wall there were 51 caissons, which were joined together, where they abutted, with watertight joints and thoroughly and securely sealed. All these caissons were carried through hardpan formation to rock and the latter leveled off to give a secure and solid horizontal bearing. All joints of the caissons after sinking and sealing were thoroughly grouted with neat Portland cement. The first dam wall caisson was started July 31, 1906, the last one completed July 17, 1907, and the average time required for sinking was 25.7 days. The original intention was to construct the main dam wall before commencing the excavation of pits for the columns of the structure, but the length of time which had elapsed in constructing the dam wall made it desirable to commence sinking the column pits while the coffer dam was in process of construction; consequently, all the column pits had to be sunk under air pressure as hollow caissons. All the column foundations were carried down to bedrock or to hardpan, and the construction of the station involved the sinking of 184 column pits in open caisson construction. Steel columns were erected in these open caisson pits, on foundations prepared for the same, before any excavation was carried below tidewater level. To retain the dam wall it was necessary to construct the floors from the street surface downward and to make secure these floors as the work proceeded. Consequently, as soon

as the columns were erected the concourse floor steel was put in over the entire area and riveted up and the concrete floor put in from wall to wall, or so much of it as would give efficient bracing between the walls east and west as well as north and south. The excavation then proceeded below the concourse floor level until the track floor level was reached, when the girders and floor itself of the track floor were placed in position, and these floors formed a strut retaining the coffer dam walls against the external pressure. It was considered essential that the vibration of trains operating in the underground station should not in any possible degree be transmitted to the buildings, and that there should be no shock or noise due to the operation of trains felt through the buildings above. A structural steel floor was therefore omitted for the main track floor,



Train in Way Station.

Concourse Level, Church Street Terminal.

and in place of this very deep and massive crossgirders were put in between the columns, and a solid floor of reinforced concrete, 36 in. in thickness, was carried continuously over the entire area from wall to wall, enclosing the main 48-in. girders as well as the columns in one continuous mass. The result has been fully equal to the expectations, as not the slightest jar, shock or noise is transmitted in any respect to the buildings by the operation of trains. The only openings in the track floor are those provided for staircases or for pipe ducts between the basement and the floors above. During the construction of this floor there was a very anxious time, owing to the failure of the steel manufacturers to supply at the time promised the girders necessary for the construction of this floor. The concourse floor is a comparatively light floor, and is not designed to bear more than its proportion of the external pressure against the coffer dam wall, and as the excavation proceeded to a point below the track floor it was noticed that the wall along the line of Church street was becoming bowed to an appreciable extent and was daily advancing in the center. The ends of this wall at Cortlandt and Fulton streets remained stationary where supported by the end walls of the coffer dam, but at the center near Dey street the thrust inwardly of the wall was quite perceptible. Before the steel was received and the track floor made complete and solid, the total movement of the wall at the center was approximately 10 in., but, notwithstanding this movement in the reinforced concrete wall, no cracks or openings have ever appeared.

On completion of the track floor, excavation was carried down over the entire area to the hardpan and all quicksand removed, regardless of whether or not it was above the permanent lowest floor level. Under the Fulton street building it was necessary to carry the excavation down to a still lower level than the basement for the installation of a boiler plant and coal bunkers, and over a large portion of the area of the Cortlandt street building it was necessary to go down to a very low level for the construction of an electrical sub-station. Over the latter area, excavation was carried down to bedrock and for some 8 or 10 ft. in bedrock to the final floor level. To relieve the basement of any possibility of lifting under water pressure in the event of water finding its way through the coffer dam wall, a complete system of under-drainage with tile pipe was put in below the basement floor with boiler ashes around the same, and below the concrete floor were laid boiler ashes over the entire area, all drainage being carried to a deep sump in the boiler room. The leakage is so minute that it is quite a negligible factor, and the total amount of water coming in through the coffer dam wall can be bailed by hand with an ordinary bailer. By draining the basement in this manner the necessity for making a massive floor that would resist the external pressures was eliminated.

The main basement floor is 32 ft. below tide level, the floor of the electrical sub-station is 51 ft. below tide level, and the floor of the boiler room is 39 ft. below tide level. The lower tiers of columns were in every case carried up to the splice above the concourse floor level, and those columns in the electrical sub-station weigh some 26 tons each. The total amount of steel construction below the street level was approximately 8,000 tons; the total number of caissons, including the interior column caissons as well as those in the main dam wall, was 198; contents of same, 52,000 cubic yards; and total excavation for foundations of the terminal, 178,000 cubic yards.

In addition to the electrical sub-station in the sub-basement with transformers converting electric current for the purpose of railway operation from 11,000 volts a.c. received through the tunnels from the main power house in Jersey City to 625 volts d.c. as supplied to the contact rail, there are also transformers for furnishing the buildings with current for lighting purposes and operating the elevators. There is also an independent isolated electrical generating plant with a battery of watertube boilers, 1,500 h. p., and coal bunkers with capacity for 1,600 tons anthracite coal, which may be delivered by chute from the street, or under normal conditions of operation will be loaded into coal cars from the power house in Jersey City through a chute and transported by cars through the tunnel to the bunkers in the basement; an ice making and refrigerating plant of the ammonia absorption type for supplying the restaurant and clubs; ventilating blower and exhaust fans, storage batteries and all necessary appliances for the efficient operation of the buildings. In addition there are installed on the basement floor, with an independent stairway for access, motormen's and conductor's locker rooms and assembly rooms, as well as a school of instruction fitted with a dummy car and signal apparatus for the railway employees. Baggage elevators are provided for receiving baggage on Dey street and delivering it to the baggage floor at the basement level, where a large space is set apart for the storage and handling of baggage. Four independent baggage elevators are installed for raising the baggage from the basement level to either one of the train platforms. It is planned to handle all baggage by loading it into vans equipped with small wheels which will be run into the baggage cars in the trains and wheeled out of the baggage

Pennsylvania Station.

cars at the point of destination at the several railway stations in Jersey City. This will obviate handling the individual pieces of baggage into and out of baggage cars in trains and will permit of more rapid operation of the baggage service than by any other plan of handling which has been considered.

All floors below the street level are continuous from Cortlandt street to Fulton street, extending under Dey street. Above the street level the buildings are divided by Dey street although the buildings themselves are connected by a bridge at the third floor level.

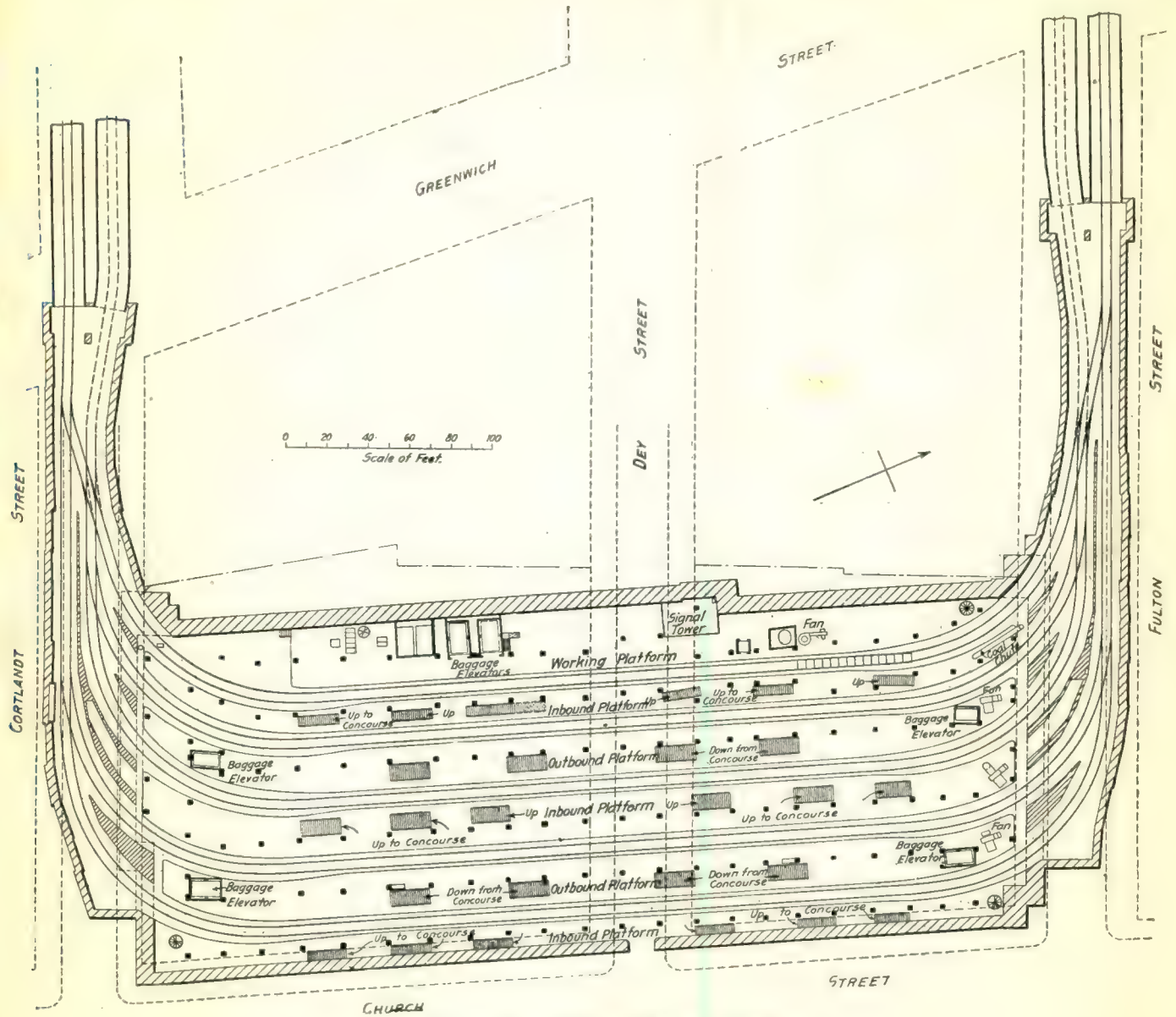
Over the entire area above the stations are constructed twin buildings, the Cortlandt building, extending from Cortlandt to Dey streets, being slightly larger than the Fulton building, which extends from Dey to Fulton streets. Each of these buildings is 22 stories high, the two upper floors of each being occupied respectively by the Railroad Club of New York and the Machinery Club. The total floor area of the two buildings is 950,000 sq. ft., first to twenty-second floors inclusive, and in the construction of the buildings above the street level there were used 14,500 tons of structural steel. The height of the buildings from the lowest basement to the towers is 381 ft. 2 in. The space enclosed by the buildings is 19,146,839 cu. ft., of which a space of 6,000,000 cu. ft. is below the street level. There are installed in the buildings 39 elevators, 22 of these being ex-

press cars, stopping only on the eleventh and higher floors, and the remaining 17 local cars making all stops from first to eleventh floors inclusive. A population of nearly 10,000 persons transact their daily business in the twin buildings.

For ingress and egress to the railway trains in the terminal there are provided four entrances and exits, each 30 ft. wide, located, respectively, one on the north side of Cortlandt street, one on the north and one on the south side of Dey street, and one on the south side of Fulton street. It was originally intended that the two openings in Dey street should be for entrance to the station and the openings in Cortlandt and Fulton streets exits, but it was found more desirable to throw them all open for the common use of the public as both entrances and exits, and the openings are so broad that the likelihood of conflict of passengers moving in opposite directions is obviated. The openings at Cortlandt and Fulton streets are constructed in the form of ramps, having an incline averaging 11 per cent., while the entrances and exits on Dey street are stairs of very easy rise. On the waiting room (concourse) floor are ticket offices of the Hudson & Manhattan and also ticket offices of the Pennsylvania, the Lehigh Valley and the Erie, selling all classes of tickets over their respective lines, and by agreement between the Hudson & Manhattan and the Pennsylvania the tickets of the latter company are honored for passage through the downtown tunnels of the former company.

Two floors in the Cortlandt building are leased to the United States postoffice department and the postal station here located forms the main outgoing station of New York City.

The approaches to the terminal station presented an even more difficult proposition to deal with than the terminal foundations, as the approach structure had to extend practically up to the building lines on both sides of Cortlandt and Fulton streets; consequently the work had to be carried on below the surface by sinking caissons enclosing the entire area and extending to a level below the track construction. This was done by sinking hollow caissons with removable end walls, the roof of the working chamber forming ultimately the floor of the tracks. These caissons were subdivided into sections the full width of construction and in lengths approximately 20 ft. each. As they were sunk they were joined together on the outside by overlapping the same with steel channels driven external to the walls and then grouting extensively with Portland cement grout. The difficulties of sinking these caissons were very great as there was no headroom for hoisting materials and a special type of air lock was designed to enable the work to be carried out. The difficulties of the work may be appreciated



Plan of Track Level, Church Street Terminal.

when it is understood that on Cortlandt street during the execution of the work there were carried on false work over the construction practically every telegraph and telephone wire leaving the downtown district of New York north, south and west, over 7,000 wires of this character being supported. In addition there were steam mains of the heating company furnishing steam heat to buildings in the downtown district, water mains, gas and electric conduits, and temporary iron pipes carrying the sewage of the district. In addition to this, the elevated railway structure of the Sixth avenue line at Cortlandt and Church streets and at Fulton and Church streets and of the Ninth avenue line at Cortlandt and Greenwich streets and at Fulton and Greenwich streets had to be supported and carried on false work during the procedure of the work, and ultimately the foundations of these two elevated railway lines were transferred to the roof of the finished tunnel structures. Further, all the buildings fronting on Cortlandt and Fulton streets adjacent to this work had to be underpinned and carried during the execution of the work. The work was carried to completion without a single mishap and without any interference whatsoever with the service of any of the various companies owning the subsurface improvements which were temporarily supported and taken care of.

In the approaches outside of the main dam wall, there were excavated 42,000 cu. yds. Of this quantity 26,000 cu. yds. were taken out under air pressure, and 16,000 cu. yds. excavated in the open. The total number of caissons forming the tunnel approaches was 32; sinking of the first one started April 23, 1907, and the sinking of the last one completed November 14, 1908. The concrete construction involved in these caissons is 11,000 cu. yds.

Illustrating Signal and Automatic Stop.

The completion of the approach caissons, when roofed over, still left the approaches cut off from the terminal station by the continuous coffer dam wall surrounding the terminal. This wall, therefore, had to be blasted and cut through, which involved the equivalent of 120 ft. of full-sized tunnel through reinforced concrete, these openings being blasted through approximately to size and the steel work cut away as the work proceeded. This involved one of the most tedious pieces of work in the whole undertaking, and it obviously could not be done until the entire construction on both sides was finished, securely jointed and sealed beyond any possibility of flood or

other disaster. While the approach work was in progress, the caissons of the westerly sections under both Cortlandt and Fulton streets being completed first, shields were erected and four tunnels started westwardly—two under Cortlandt street and two under Fulton street. Of these four tunnels, one under Cortlandt and one under Fulton street continued westward towards the river and met the tunnels already proceeding from the New Jersey side. The other tunnel in each of these two streets was continued a sufficient distance to permit of work being resumed at a later date on the tubes direct to the Erie Railroad without interference with the tubes now in operation.

TRACK.

Generally speaking, the standard track throughout all the lines of the company consists of white oak ties, laid in broken trap rock ballast on a flat surface of concrete forming the invert. This concrete invert fills the flanges between the plates in the tube tunnels and a drain is formed with a reinforced concrete slab over the same along the center line of the tunnel, which provides efficient drainage of the tunnel.

The rails are 85-lb. A. S. C. E. section with Continuous rail joints, and all rails are attached to the ties with screw spikes of special design for this company's work. Goldie tie plates are used throughout, the plates being put on the ties to exact template spacing under hydraulic pressure before the ties are sent into the tunnels. Holes in the ties for the screw spikes were bored with a pneumatic auger before the ties were taken into the tunnels, and the screw spikes put in place and driven with a pneumatic screw driver which proved very rapid in operation and of great efficiency. This tool was designed by officers of the company for the particular use to which it was put.

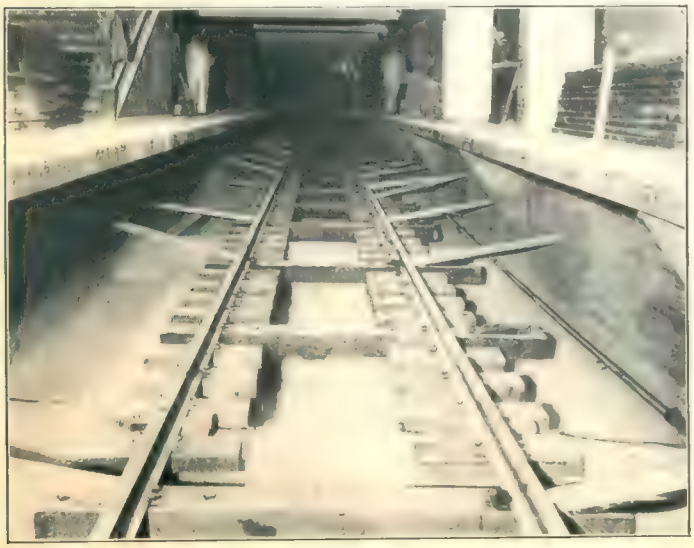
All the rail used in the downtown tunnels has been 0.90 per cent. carbon manufactured by the open hearth process by the Bethlehem Steel Company, and on heavy curves either chrome nickel or manganese rail was used, according to the radius of curvature.

The contact (third) rail is of special type, designed by L. B. Stillwell, the company's consulting electrical engineer. This rail is carried on heavy porcelain insulators, and secured by pressed steel brackets to long ties spaced about 10 ft. apart. The contact rail is protected by an overhanging board of Australian jarrah wood.

At heavy curves and in the downtown terminal, as well as at special points where reinforcing was executed, the track was laid in solid concrete.

Guard rails are installed on all curves of less than 750 ft. radius, these rails being 100-lb. section A. S. C. E. and 9-16 in. higher than the running rail.

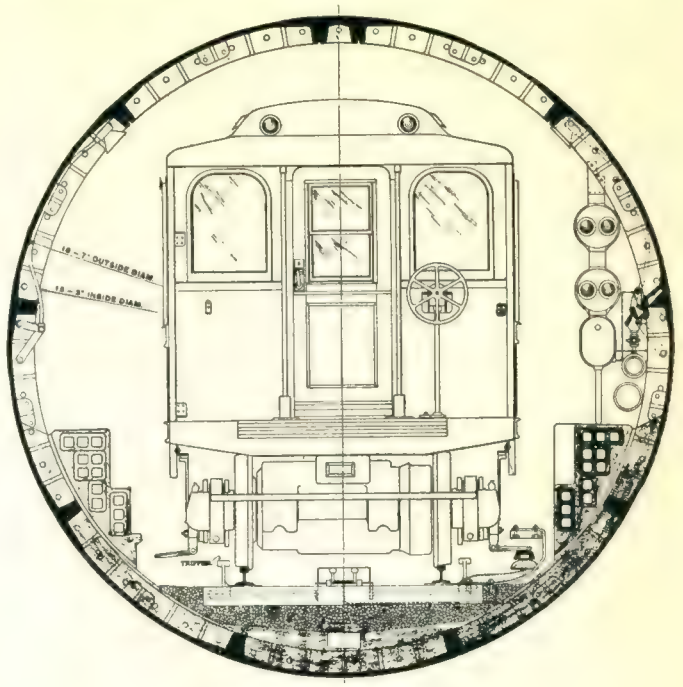
All frogs and switches are of manganese steel.



Track at Church Street Terminal Under Construction.

DUCTS.

Electric ducts are carried throughout all tunnels in such number as needed by the electrical department, but arranged in all cases in internal benches within the lining of the tunnels. The right hand bench wall in the direction of train movement carries all equipment of every kind, such as signals, air



Signal and Automatic Stop.

pipe lines and pump discharge lines, etc., leaving the left hand bench wall clear for employees or for a walk-way for persons in case the necessity arises. The ducts throughout are vitrified tile ducts, 3½ in. square, with rounded corners and grouped between manholes as most convenient in each particular section of the tunnels.

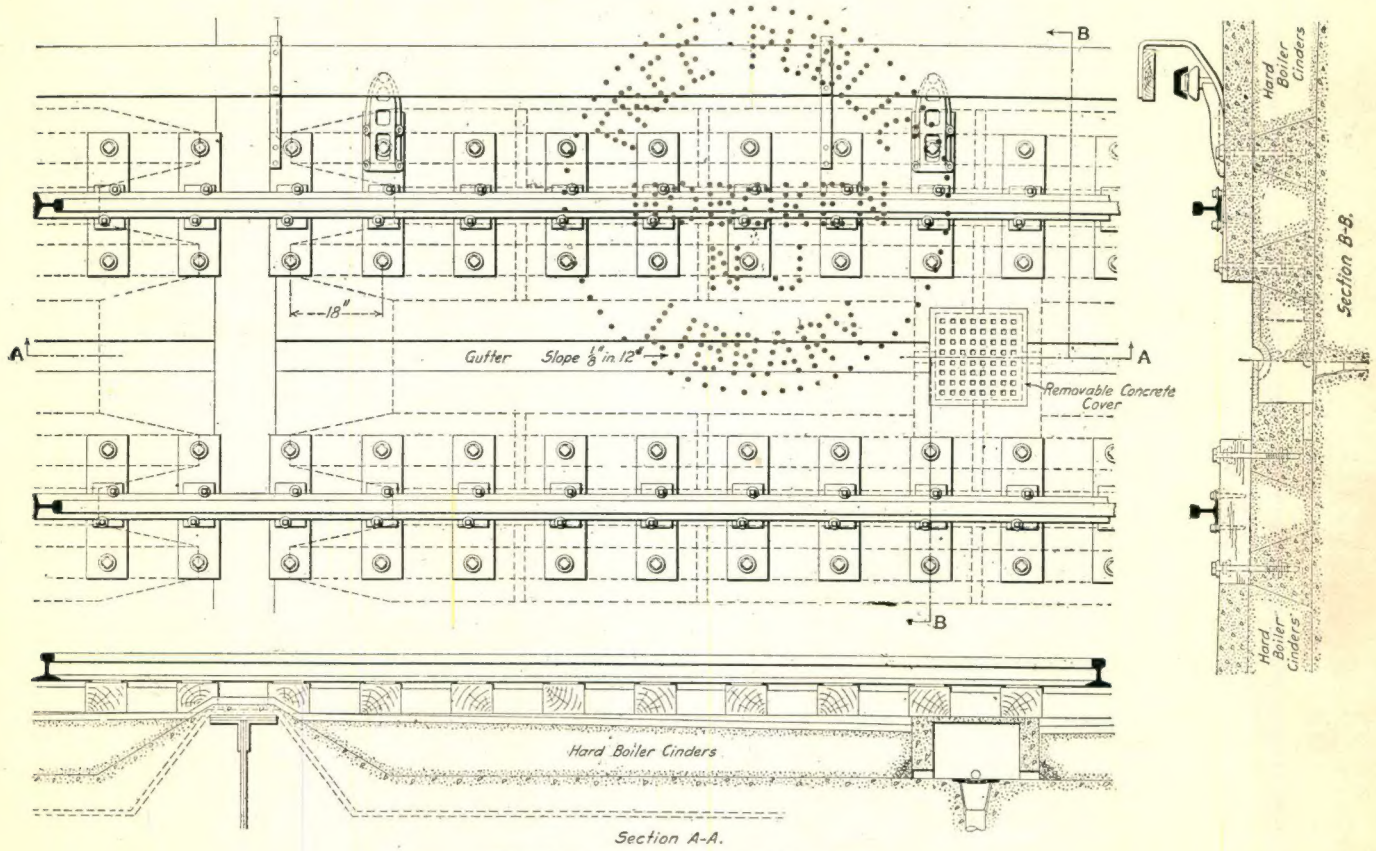
Finished Track at Church Street Terminal.

SIGNALS.

The signal system throughout is arranged for operation of eight-car trains on headway of one and one-half minutes in either direction and on all lines. The signals are arranged with single overlap and there is a full equipment of automatic train stops.

On the uptown line, between Hoboken and Twenty-third street, New York, the signal installation was by the General Railway Signal Company, and consists of an all-electric system with the Kinsman electric-motor operated train stops and electrically operated visual signals. The interlocking plants in this installation are also electrically operated, and illuminated track models are installed at each interlocking tower.

For the downtown work, however, the installation was made by the Union Switch & Signal Company, and the equipment is electro-pneumatic, including the train stops. An illuminated track model at the Church street terminal indicates the entire movement in both tunnels between the Pennsylvania station, Jersey City, and the Church street terminal, New York. A similar model at the Pennsylvania station indicates all diverging and converging routes at the Pennsylvania station and the movement westbound from the Church street terminal, but does not indicate the eastbound movement after trains clear the Pennsylvania station.



Track at Church Street Terminal.

VENTILATION.

The general principle adopted throughout for the ventilation of all tunnels is for the removal of air forced through by the trains under the piston effect in advance of trains and forcing in fresh air behind a retreating train. These ventilating plants are installed at points of junction between tubes, where the air would otherwise mix or short circuit. For this purpose there are ventilating plants arranged as follows:

Ninth street. There is a suction and blower plant arranged for this junction.

Christopher and Greenwich streets. There is a blower plant at sub-station at this point.

Morton street. There is a suction plant drawing out air from the eastbound tunnel at the foot of this street, with an uptake through a shaft to the street surface.

Fifteenth street, Jersey City. At this point there is a suction fan installed exhausting air from the westbound tunnel from New York.

Hoboken terminal. There is a fresh air blower plant at this location supplying air into the southbound (also eastbound) tunnel.

Church street terminal. At this point there is a suction and blower plant. The suction plant draws the air out of the eastbound tunnel below the tracks, discharging into the open air, and the blower plant exhausts air out of the center of the terminal station and forces air into the westbound tube in the rear of departing trains.

This system of ventilation, as carried out with the tube system, has proved thoroughly efficient.

WATERPROOFING.

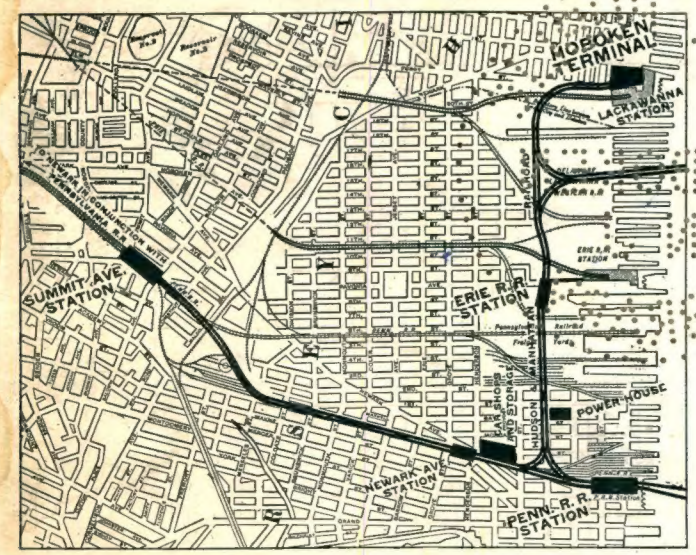
Wherever work is executed by open-cut methods the structure is waterproofed with fabric and pitch applied in the usual manner, making a complete envelope around the structure As the greatest part of this work, however, was executed by tunnel methods this manner of waterproofing was not feasible, excepting in small portions of the work. The method, therefore, adopted was invariably to grout with Portland cement in the rear of the plate lining or concrete lining, and in the majority of cases this application answered the purpose of making the tunnels perfectly watertight. Owing to the imperviousness of neat cement this was the only waterproofing adopted on the coffer dam walls on the Church street terminals and approaches. In the iron-lined sections of tunnel all joints of the plate segments were first grummeted on the bolts with flax and red lead under the bolt washers, and caulking spaces between the joints of the plate lining were first caulked with a thread of lead wire, followed up and supported with rust joint cement. Throughout the concrete work waterproofing wa

done by plastering on the internal and exposed surface with one of the usual types of waterproofing compounds mixed with neat Portland cement and applied with a trowel, this method answering admirably in a majority of cases. At the same time, in persistent leaks, it was found necessary to cut right back into the concrete and expose the voids and then reconstruct such portion of concrete with a rich mixture of cement. As a general rule, for waterproofing of concrete work a rich mixture of cement in the concrete with thorough and efficient ramming has answered the purpose and constituted the only waterproofing used.

INSTRUMENTAL WORK.

The laying out of the work in the field, owing to the construction being entirely underground, had to be carried out with great care particularly in projecting the surface surveys underground in the narrow shafts by means of wire lines.

Triangulation surveys across the river were carried out for the uptown lines, as well as for the downtown lines, and these



New Jersey Lines, Hudson and Manhattan Railroad.

triangulation surveys connected together and also joined up on either side by land surveys between. The location of the uptown tunnels enabled a complete quadrilateral to be laid out with base lines measured on both sides of the river, checking one against the other, and the underground surveys were carried through from a direct wire line joined in upon one of the base lines of the triangulation survey, the wire lines being on the direct surveyed line. This made the instrumental work for the uptown tunnels comparatively easy, and the lines extended all the way from New Jersey to New York joined within 1 in. in alignment.

On the downtown tunnels, however, the difficulties were very much greater. There are curves in the tunnel alignment at each end, so that direct lines from end to end underground were not possible. Further than this, at neither end was it possible to project the surface surveys underground on the axis of either tunnel as the shafts were to one side. At the New Jersey end one wire line was plumbed, using fine brass wire and heavy lead wing weights, oscillating in water baths at the vertical shaft at Pier C. A 10-in. pipe was driven down from the surface at Exchange Place, Jersey City, into the cross-heading used for construction purposes and the other wire line plumbed through that pipe. This constituted the base line from which the surveys were carried underground.

On the New York side, similarly, wire lines had to be plumbed down at different points in the streets on a line turned from the triangulation survey, and the direction of the underground surveys had to be calculated to give the direction for the underground survey lines. This extremely difficult piece of work was carried out by two independent corps working at different times and checking each other, and their work was so accurate that the first tunnel driven through (south tunnel) joined within 0.16 ft. in line and 0.004 ft. in grade.

All these surveys were carried on at night on account of the reduced interference by outside conditions and the better atmosphere in which to carry on the surveys. In addition to this, all base line measurements were carried on at night, as the more uniform temperature at that period of the day also added to the accuracy of the work.

ORGANIZATION.

Since the year 1902, when the work was taken over by the present company, it has been executed with the company's own organization.

The president of Hudson Companies is Walter G. Oakman, and the vice-president and treasurer, William Henry Barnum.

The president of the Hudson & Manhattan Railroad Company is William G. McAdoo, and the vice-president, Wilbur C. Fisk.

The chief engineer of both the Hudson Companies and the Hudson & Manhattan Railroad Company was Charles M. Jacobs, member Institution of Civil Engineers and American Society of Civil Engineers; and the deputy chief engineer, J. Vipond Davies, member Institution of Civil Engineers, American Society of Civil Engineers, and Canadian Society of Civil Engineers. These gentlemen are of the firm of Jacobs & Davies, Inc., consulting engineers.

The staff was divided into two general departments—engineering and construction—both reporting directly to the chief engineer and the deputy chief engineer.

The engineering department had at its head the principal assistant engineer, whose staff consisted of an engineer of design, a chief draftsman, three division engineers with the necessary corps of assistant engineers, resident engineers, instrumentmen, rodmen, chainmen, inspectors, etc. This department was charged with the design, survey, inspection, setting out, estimates, records, etc.

The construction department was divided into five divisions at the head of each of which was a works manager, and each works manager had a full staff consisting of a master mechanic, superintendents, assistant superintendents, chief electricians, electricians, walking bosses, foremen, mechanics, laborers, etc. This department had actual direction of the workmen, the ordering of materials and supplies, the operation of the power plants, etc.

The electrical installation and car equipment have been designed and constructed under the direction and supervision of Lewis B. Stillwell as consulting electrical engineer, with Hugh Hazelton as electrical engineer and John Van Vleck as mechanical engineer.

The project since the year 1902 has been financed to completion by Harvey Fisk & Sons, New York City.

ADDENDA

The above was written in 1909 and published in Railroad Age Gazette for September 17, 1909; September 24, 1909; October 1, 1909; October 8, 1909; October 15, 1909, and October 22, 1909, and as reprinted here typographical errors have been corrected and certain minor alterations have been made and the following additional facts are given in order to bring the information to date:

ORGANIZATION.

On August 1, 1909, an addition was made in the engineering organization by the establishment of the office of Consulting Chief Engineer, which was filled by the advancement of Charles M. Jacobs, chief engineer. J. Vipond Davies was advanced from deputy chief engineer to be chief engineer, and James Forgie, of the firm of Jacobs & Davies, Inc., member Institution of Civil Engineers, American Society of Civil Engineers and Canadian Society of Civil Engineers, was appointed deputy chief engineer.

DATES OF OPENING TO TRAFFIC.

The uptown tunnels from Hoboken to Nineteenth street and Sixth avenue were opened to traffic on February 25, 1908, comprising 6.2 miles of single tracks. On June 15, 1908, the line was opened to Twenty-third street station, using the easterly side of the station only. On July 19, 1909, the downtown river tunnels from Church street terminal, New York City, to Pennsylvania station in Jersey City were thrown open to traffic, and on August 2, 1909, the link connecting the uptown and downtown systems on the New Jersey side was placed in operation and on September 20 the tunnels between Caissons No. 1 and No. 3 were opened which enable the uptown system to send trains to and from the Erie station and the Pennsylvania station and at the same time the west side of Twenty-third street station was placed in use. The total length of single track in service at this time being 12.79 miles.

On September 6, 1910, the Henderson street station in Jersey City with the connecting tunnels to the Pennsylvania station and Washington street line were placed under operation, together with the car storage yard and approach thereto. On November 10, 1910, the line on Sixth avenue to Thirty-third street was completed, making the complete length of single track in operation 15.61 miles with 1.91 miles of storage tracks.

EXTENSION ON SIXTH AVENUE.

Work on Sixth avenue proceeded actively, working from the southerly end northward until the financial panic of 1907, when work was underway as far as Twenty-seventh street, at which time the management decided to complete the work that had been started, but not to open up any new work north of Twenty-seventh street until the conditions were more favorable and until some definite decision could be arrived at as to the treatment of the Thirty-third street station. This station was originally designed to be on property purchased by the company on the easterly half of the block on the west side of Broadway, between Thirty-second and Thirty-third streets. A further study of the situation led to the conclusion that a suitable station could be built in the street and the cost of the property saved, and a design was made for a three-track stub end station without a concourse, the rails being placed at an elevation as near the surface of the street as the structure would admit.

In the meantime it was decided that to logically carry out the function of the road as a connecting link between the steam railways terminating in New York that it should be extended to the Grand Central terminal on Forty-second street and application was made to the Public Service Commission for a franchise to permit this, which was granted on May 4, 1909. This necessitated that the design of the Thirty-third street station should be reconsidered so as to permit of it serving temporarily as a terminal and at the same time be so arranged that the proposed extension could be made. The level of the rails was lowered so as to permit of the construction of an overhead concourse and switching enlargements provided to permit of trains being reversed.

The property purchased for a station having been sold for the purpose of constructing a department store, space in the basement was reserved for the storage and handling of baggage and also the right to construct stairways and conveyors to the street level.

Authority to proceed with the work north of Twenty-seventh street was received in August, 1909, and was actively pushed to a completion within fifteen months.

With the exception of the Thirty-third street station the work was executed in practically the same way as that previously finished. The construction of the station itself involved some novel features. As it occupied the full width of the street and extended to a depth below the foundations of the adjoining buildings, it required the careful temporary support of these and the underpinning of some to this deeper level. The lowering of the level of the station required that the three-track arch of the Pennsylvania tunnel on Thirty-second street be removed and in place thereof the new tunnel and the street above were supported with heavy steel girders.

The station was arranged with three tracks and four platforms so that the loading and unloading could be separated. Groined arch construction, supported by steel columns, was used throughout. These steel columns were enclosed in cement slabs, which were moulded and cast, and then erected so as to give the appearance of solid stone or concrete. The railings and ballustrades were treated in a similar way so as to give the same a harmonious effect.

RAILROAD AVENUE AND HENDERSON STREET STATION.

Work had just been fairly started on the Henderson street station when the panic of 1907 caused the suspension of this work, as well as that on the tunnels connecting same to the Pennsylvania station and the Washington street line.

Orders were given to resume work in August, 1909. The driven tunnels connecting the Henderson street station with the Pennsylvania station and the Washington street line had previously been driven from the Pier C shaft and the Washington street shaft, but as the tunnels were now in operation past these shafts the incompleted workings were not accessible from same, so it was necessary to construct a new shaft on Railroad avenue west of Warren street, with a crossheading connecting same to the tunnels.

Work was actively pushed by driven tunnels to Henderson street and by cut and cover methods west of Henderson street, and was extremely difficult in both places. The driven tunnels were in water bearing material below tide level with the embankment of the Pennsylvania Railroad overhead over which their heaviest passenger trains were operated. Compressed air was used and the tunnels were driven by ordinary soft ground methods without shields, and were lined with concrete. In addition to the standard tunnels two junction enlargements, each 124 ft. long, with a maximum width of 29 ft., were built.

The Henderson street station was constructed between Henderson and Grove streets and consisted of a series of groined arches supported by standard steel columns. This work was rendered more difficult owing to it being beneath the four-track viaduct of the Pennsylvania Railroad. This viaduct is supported by bents of three columns each, spaced from 40 to 50 ft. apart. The load on each column is about 600,000 lbs. The method of procedure was to support a bent by three pair of steel girders 7 ft. deep and 69 ft. long resting on temporary special footings, to excavate a slice under the bent to grade, then to build a complete section of station with concrete or steel supports extending from the roof to support these columns. After allowing sufficient time for the concrete to set the girders were removed and the process repeated at another bent. When sections of the station were completed at two adjoining columns the space between same was excavated and the structure completed. Immediately west of the Henderson street station was constructed a switch enlargement to permit of a scissors crossing so that trains could be reversed at this point. At the easterly end of the station another junction enlargement was installed with a branch tunnel extending to the car storage yard constructed on the surface in the block bounded by Henderson, Warren, Steuben streets and Railroad avenue. In this yard are located the inspection shed with provision for inspecting two eight-car trains and the car repair shops, and tracks for the storage of 96 cars.

West of the station the standard tunnel was constructed by similar methods to those used for the station as far as Barrow street, to provide switching length for a train.

RAILROAD AVENUE WEST OF BARROW STREET.

West of Barrow street the tunnel continues under the tracks of the Pennsylvania Railroad to a point near Prior street, where it emerges to the surface and the tracks will connect to those of the Pennsylvania, over which the tunnel trains will be operated to Summit avenue, where a station will be built with provisions for exchange of traffic with the surface lines of the Public Service Railway. From this point the Pennsylvania Railroad will operate an electric service to Manhattan Transfer, where passengers can transfer to and from the trains moving into and out of their new terminal in New York, and also to a new station at Saybrook Place in Newark.

Work west of Barrow street was continued by methods similar to those used east thereof, excepting for a short distance near Monmouth street, where owing to quicksand it was necessary to install compressed air. West of Brunswick street the inclined approach from the tunnel to the surface was built partly by tunneling with compressed air and partly by cut and cover methods. The whole will be completed and placed under operation during the summer of 1911.